When timber production comes out of the woods: Post-forestry states in wood and forest socio-ecological systems

by

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Declaration of originality

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

Russell Denis Warman

26/05/2017

Authority of Access

Statement of co-authorship

The following people and institutions contributed to the publication of work undertaken as part of Russell's candidature:

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Papers included in thesis

Paper 1: Is wood production coming out of the woods? The resilience and transformability of forestry
Parts in Chapters 3, 4 and 10
Candidate was the sole author of this paper.

Paper 2: Global wood production from natural forests has peaked
Mainly in Chapter 5
Candidate was the sole author of this paper.

Paper 3: Forest conservation, wood production intensification and leakage: An Australian case?
Mainly in Chapter 6
Candidate conceived paper idea, conducted literature reviews, data collection and analysis and was primary author (90%).
Author 3 contributed to writing and theoretical/conceptual development (10%).

Paper 4: Decentralization and forestry in the Indonesian archipelago: beyond the big bang
Mainly in Chapter 7
Candidate was the sole author of this paper.

Additional papers written during candidature but not part of thesis

Do timber plantations contribute to forest conservation?
(For reference, included in Appendix A)
Candidate invited to be independent referee of a Centre for International Forestry Research briefing note, was subsequently invited to co-author paper based on this briefing note and feedback provided and led the rewrite into a paper (33.3%).
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Author 2 led literature review and briefing write-up and contributed to review of paper (33.3%).

Disrupting polarised discourses: How to get out of the ruts of environmental risk conflicts?
(For reference, included in Appendix B)
Candidate co-authored paper (50%).
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(It is the intention of Author 4 to submit this paper as a chapter of her thesis.)

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Dedicated to the world's forests, their inhabitants, dependents and lovers.

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Thesis by publication and traditional thesis—a hybrid approach

Parts of this thesis were written first as papers or conference presentations. However, the thesis itself has been prepared as a manuscript thesis rather than as a standard thesis by publication (a series of published papers bookended by an introduction and conclusion). The following table specifies the published works. In addition, several conference presentations have been made as part of my PhD candidacy in which various parts of this research have been presented. As noted above, four papers have been largely reproduced in this thesis. Two additional papers (in grey), written during the candidature, have been treated as cited material in the main thesis and are included in the appendix for reference (note also, their references are not included in the main thesis reference list).

Journal Article - published
Pirard, R, Dal Secco, L & Warman, R 2016, 'Do timber plantations contribute to forest conservation?', *Environmental Science & Policy*, vol. 57, pp. 122-30.
Warman, R 2016, 'Decentralization and forestry in the Indonesian archipelago: beyond the big bang', *South East Asia Research*, vol. 24, no. 1, pp. 23-40.
Warman, RD 2014, 'Global wood production from natural forests has peaked', *Biodiversity and Conservation*, vol. 23, no. 5, pp. 1063-78.
Warman, RD & Nelson, RA 2016, 'Forest conservation, wood production intensification and leakage: an Australian case', *Land Use Policy*, vol. 52, pp. 353-62.
Journal Article – in review
Lucas, C & Warman R in review, 'Disrupting polarised discourses: how to get out of the ruts of environmental risk conflicts' Submitted to *Environmental Politics* February 2017.
Warman, R in review, 'Is wood production coming out of the woods? The resilience and transformability of forestry'. Submitted to *Forest Policy and Economics* September 2016.

Presentation title	Conference	Place, date
Is wood production coming out of the woods? The resilience and transformability of forestry	IUFRO International and Multi-disciplinary Scientific Conference – Forest-related policy and governance: Analyses in the environmental social sciences	Bogor, Indonesia 2016
Forest conservation, wood production and leakage: An Australian case study	" "	" "
Intensive wood production and its potential for benefiting non-wood values in extensive forests (Session Chair)	" "	" "
Land sharing in wood production and implications for forests	School of Land and Food Annual Conference	Hobart, Australia 2016
Getting out of the ruts of polarisation in environmental conflicts (co-presented with Chloe Lucas)	" "	" "
Resilience and transformability of forestry	School of Land and Food Annual Conference	Hobart, Australia 2015
The transition of wood production in Indonesia	School of Land and Food lunchtime lecture Series	" "
Peak wood production from natural forests	Guest presentation at Centre for International Forestry Research, Bogor	Bogor, Indonesia 2015
A fresh approach to tackling nature conservation / resource use conflicts: lessons from the Tasmanian forest 'peace' talks	World Parks Congress	Sydney Australia 2014
Leakage of logging activity resulting from changes in reservation of forests in Australia	Geography and Spatial Sciences Annual Conference	Hobart, Australia 2014
Global peak production of wood from natural forests	" "	" "
Leakage effects of forest policy in Australia - Poster presentation	6th International Ecosystem Services Partnership Conference	Bali, Indonesia 2013

(The word ‘clouds’ at the start of each part of the thesis were generated using the text of the part of the thesis that follows. They are formed using the most commonly used words in each section. The diagram on the cover page uses the text of the abstract. They were generated on website https://tagul.com/.)

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Abstract

Wood production is changing from extraction out of natural forests to cultivation of wood that is increasingly agricultural in nature. This has significant implications for wood/forest socio-ecological systems. This thesis takes a multidisciplinary approach to examine the socio-political, biophysical and cultural/discursive dimensions of change in these systems. A heuristically derived model of three sequential states, or conditions, of wood/forest socio-ecological systems is developed. The model challenges the historical integration of wood production and forest management exemplified by the institutions of 'forestry' with their inherent wood/forest nexus. This provides a conceptual frame to support analysis of system change and its influences. Research here shows that global wood production from natural forests peaked in 1989, with cultivated wood sources making up an increased portion of the world's wood production since. This change allows growing demand for non-wood values from extensive forests to be met. The institutions of stewardship forestry were founded on normative ideals of sustainable systems in long term equilibrium. However, these occur within rapidly evolving social contexts and changing values. This creates considerable tension within wood/forest socio-ecological systems and their institutions and governance, notably, a tension between increasingly unviable attempts at adaptation of existing systems and the potential transformation of systems to new states. Transformation, however, requires willingness to consider post-forestry conditions, such as integration of wood cultivation into landscape approaches, rather than the forest-centric approach of stewardship forestry, and increasing management of extensive forests for non-wood values in the absence of wood production.

Part 1: Introduction and context

1 Introduction

The rudimentary enterprise of entering a forest, selecting a tree, and removing wood has been a staple activity through much of human history. It has been remarkable for its endurance against the dramatic changes in so many other areas of human endeavour. But increasingly, sourcing of wood around the world is undergoing a fundamental shift, from being sourced in natural forests, to increasingly sourced from plantations and other cultivated trees. This shift is analogous to the evolution of agriculture emerging from earlier methods of food collection from wild ecosystems (Binkley 2003; Carle, Ball, and Del Lungo 2009; Sedjo and Lyon 1983; Sutton 1999). For wood, this process begun to occur in the last few centuries in densely populated parts of the world such as West Europe, Java and Japan. The shift to cultivated trees[1] for wood production gathered pace in the twentieth century (Evans 2009).

The transition in wood production is occurring in response to technological and economic factors pushing wood sourcing to more cost effective and productive methods (for example Ajani 2011b; Meil et al. 2007), as well as investment in plantations and other forms of tree cultivation. Combined, these in turn could then lead to reduced wood demand from existing natural forests (Hyde, Amacher, and Magrath 1996; Sedjo 2001; Sohngen, Mendelsohn, and Sedjo 1999). As well as shifts in wood demand, demand for non-wood ecosystem services and values from forests is growing. On the one hand, this is due to increasing appreciation of forest values such as biodiversity conservation, ecosystem services (including carbon management) and tourism and recreation (Franzen and Meyer 2010; Givens and Jorgenson 2011). On the other hand there are

[1] The term 'cultivated trees' is used here to include plantations, planted forests, and trees outside forests—that is, all significant sources of wood from trees outside natural forests.

decreasing areas of forest to deliver these values due to a loss of forest to agriculture and urban expansion (Lambin and Meyfroidt 2011). Natural forest wood production is facing a squeeze between two pressures, then—the economic pushes to cultivated wood and a social and ecological push to optimise non-wood production values from natural forests.

There is a large body of literature focused on the environmental, economic and social values and impacts of timber production in both natural forests and plantations. Despite this, the body of knowledge about the transition is limited. In part, it is speculated here, this is because there has also been a tendency for wood production, forestry and forest conservation analysis to be grounded in notions of sustainability, balance, and stability. However, this is fundamentally at odds with the patterns of change in the social, technological and environmental systems within which these activities occur. Better understanding of the process of change will provide considerable opportunity for improved policy in the often intense debate around wood production from both natural and plantation forests.

1.1 Research aim and questions

The broad research aim of this thesis is to improve understanding of the process of the transitions in resource use regimes. This has been delimited to the case of a single global resource use system—wood and forests. The thesis is an examination of the global transition of wood production from extraction of wood from natural forest to cultivated wood sources.

The research was structured around three questions:

1. *Why is the transition occurring*? In particular, what are the changing historical, environmental, social, political and economic factors driving this?
2. *To what extent is the transition occurring*? Including, to what extent is it likely to occur into the future?
3. *What are the implications of this transition?* In particular what are the implications of this for the future management of forest and of wood production?

The answering of these questions aims to illicit insight that can contribute to a better understanding of transitions in wood and forest use systems as well as other natural resource use transitions.

1.2 Thesis overview

> *That a delicate shuttle should have woven together the heavens, industry, texts, souls and moral law – this remains uncanny, unthinkable, unseemly* (Latour 1993, p. 5).

This thesis set out to tackle the research question with no set discipline in mind—the focus was not grounded within one chosen discipline but ranged the disciplines to answer the above research questions. In doing this the thesis delved into economics, politics, sociology, geography, ecology, conservation biology and, of course, forestry. It eschewed the institutional reflex to delimit the research project by focusing on a singular approach, discipline, or set of data. Instead, it sought what could be illuminated when the phenomenon being studied and critiqued was viewed as a woven network approached from multiple directions. Of course, this still required delimitation, undertaken as set out in the following description. But, it allowed an immersive approach into the network nature of the phenomena being studied.

Approaching the network of wood production and forest use systems led to a structuring of the thesis into four parts. After this introduction, Part 2 is a review of the transition as described in the literature and a consideration of suitable theory and disciplinary approaches. The literature review chapter, Chapter 2, is conducted by way of an environmental history that captures the substantive phases and qualities of the transition. It focuses on the broad sweep of human use of wood and forests and the changing interconnections between the two. It was undertaken to facilitate engagement with the literature of forests, forestry and wood use. Chapter 3 is a review of the relevant theoretical dimensions applicable to the transition. In particular, it reviews the range of theoretical models used to explain land and resource use change that is occurring in relation to forests and forest use. Finally in Part 2, Chapter 4 proposes a heuristically derived model of the transition. It uses resilience thinking as a source of theory that describes complex systems and their emergent properties and how they can be both resistant, and resilient, to change. This theory is used as a basis for describing the sequence of different states for wood production and for forest use social and ecological systems (hereafter called wood/forest socio-ecological systems).

Part 3 conducts a series of case studies of the transition. It starts with a global analysis, and then shifts attention to three national studies: Australia, Indonesia and New Zealand (Figure 1). The three countries were initially chosen both for their proximity to the author's research institute (Tasmania, Australia) and for their relative stages in the transition. The first chapter of Part 3 is an analysis of the global pattern of wood production from natural forests over the last several decades. The analysis is undertaken to ascertain the extent of the transition. From there, the three detailed examinations of the transition are undertaken, with each national case study undertaken with a different approach. Bruno

Latour notes in *We have never been modern* (1993) that there are 'three tacks' critics can take when 'talking about our world': naturalisation, socialisation and deconstruction. He says there is a 'common sense' to this 'critical tripartition' that helps illuminate these networks of things and relationships that are '*simultaneously real, like nature, narrated, like discourse, and collective, like society*' (Latour 1993, p. 6 [author's italics]). Australia is examined looking at the nature of change in forest use patterns from a land use science perspective. Indonesia is approached from a socio-political perspective looking at the history of institutional change in forestry and shifts in related power relations. Then, New Zealand is considered through a discourse analysis of the writings of foresters over a nine decade period in which wood and forest use systems underwent major changes.

Figure 1. Location of three case study countries: Australia, Indonesia and New Zealand.[2]

Part 4 then considers the potential contributions and conclusions that might be drawn from this thesis. It does this in two chapters. The first considers the theory

[2] Map modified from original vector file downloaded from http://www.d-maps.com/m/world/centrepacifique/centrepacifique14.ai

implications and limitations of the research. In particular it provides some detailed discussion of the implications of changes in wood production for forest conservation. The final chapter notes limitations of the research, future research possibilities and presents some policy considerations. It finishes by noting the reflexive role of this research and its constitutive role in the future development of its topic of study.

1.3 Methods, grounding and scope

> *We suspect that most of us have a tendency to develop our pet ideas based on emotions and intuition and then use our science for support* (Sheil and Meijaard 2010).

My personal motives for the research project were to better understand the transition of wood production and what this might mean for forests, both in itself, and more broadly as a case study for other resource use system transitions. A clear set of research questions was understood from the start. A hypothesis was developed that the transition of wood production from natural forests to cultivated wood sources represented a viable path to achieve both ongoing wood demand and to better deliver forest conservation outcomes. To be most effective this involved managing the transition in such a way as to optimise these goals as well as managing other impacts associated with the changes. I also saw it as an important look at how society responds to limits of natural resources through changes in technologies and institutions. In this way, the thesis itself is a singular case study of resource use change (other cases being, for example, fossil fuels, water, arable land).

Thus, the core method employed in this thesis is the case study. Yin (2003) asserts the value of the case study as a method is in answering 'how' and 'why'? questions. This aligns with the first research question: why is this transition occurring? As well as the broader case, of the forestry transition globally, there are then three case studies of specific countries—Australia, New Zealand and Indonesia. In addition to this core method a diverse range of research tools has been deployed. This thesis includes analysis that is both quantitative and qualitative. At times analysis has included the use of basic descriptive statistics, content and discourse analysis and literature reviews. As a research method it has at times taken on the spirit of a grounded analysis as described by its immersive nature.

As noted above, the disciplinary approach here was not to situate this analysis within any one discipline, but to start with the problem(s)—what can we know about this transition and what does it mean for those who manage and use our forests?—and then use whatever discipline and methods best answer the questions and achieves the research aim. In the words of *Freakonomics* author, Steven D. Levitt, it is 'adisciplinary' (2006, p. 247).

In the final months of writing this thesis I came across a poem I had written thirty years earlier. It had a particular resonance with my thesis as it was about a personal and formative interaction with forests and plantations in my youth. Here is a brief extract:

> *These fields of radiata*
> *Who once I scorned,*
> *As the planters took the old bush*
> *I have come to see in night and day, rain and shine,*
> *Have taught me of the true beauty,*
> *That exists in all things.*
>
> (Warman 1988)

The poem describes a major change in how I valued things. Plantations of *Pinus radiata* that I had once 'scorned' for replacing the extensive indigenous wallum and bloodwood forests that I (and my parents) had grown up with, were 'destroyed'. And yet, through time and experience those same plantations came to be something that I embraced. The poem describes how, after spending extended periods of time in these new wood crops, I was left with a fondness for this particular landscape of monocultural plantations. How I valued the plantations had changed profoundly. Looking back, it now seems likely that this, in turn, shaped perceptions that, twenty years later, would have me act as an advocate for a solution to conflict over the management of forests in Tasmania, my adopted home state. In particular, this involved using plantations as a source of alternative wood to that coming from the natural forests that were logged at the time. And this experience brought me to the writing of this thesis.

I have included this poem here to help make three points. First, because it acknowledges that this entire work is shaped by myself—a unique space at which a multitude of effects has confluenced. In this, it acts as a momentary jolt to the impersonal nature of so much of the scientific enterprise. It is a reminder of the presence of the human, each with distinctive and evolving histories and values, and the messiness and irrationality that entails. Choices we make are based on values—and values change. They are not immutable, neither our own values, nor the shared values of our discourse coalitions or our societies. It is relevant because it is useful at times to acknowledge some of the messiness of science. This messiness often remains hidden within the finished black box as might be presented in the impersonal pages of the paper, the monograph, the thesis[3]. Finally, the poem's self-reflection speaks of the reflexivity involved in taking research findings and turning them out into the systems studied.

[3] The sociologist of science, Robert Merton (1968, p. 4), wrote of the 'rock-bound difference between' the products of finished science and the 'intuitive leaps, false starts, mistakes, loose ends, and happy accidents that actually cluttered up the inquiry'.

As well as the above, my work here is informed by the following values. I see the world as an unfolding evolutionary phenomenon. I consider change is central to the nature of being, at a personal, social and impersonal biophysical level. I also see the world's systems and their expressions of cultural and biological diversity as profoundly beautiful and valuable. While I will not discuss this any further in the thesis I have recorded it here to give some sense of why I might choose to analyse the problem that I have and in the way that I have. In as much as a future for the topic of study might be shaped through my agency (either directly or through others following my findings or recommendations), it is useful to understand where I was 'coming from' in choosing this topic, this approach, these data and these recommendations.

Finally, as part of setting the scene for this research, here are some reasons why it is set up as a global analysis. Wood and its history are entwined with the rise of globalisation. And yet, much forest science, economics and analysis has been undertaken at a national or sub-national level. The sovereign state has been a key part of social science analysis, both as a unit to study in itself, and as the basic unit for understanding global or international affairs. However, a contrary reality of global systems exists (for example Beck 2005b; Nash 2010; Wallerstein 1974).

The world systems theory of Immanuel Wallerstein (1974) questions the validity of understanding the modern capitalist world economy through studying the dynamics of individual states. Instead it proposes a holistic global social system where trans-state processes are central to understanding (Chew 1992, p. 4). The theory has found favour among development theorists particularly and researchers more generally in developing countries (Martínez-Vela 2001). In the sphere of wood production and forests the development of ideas of the global forest regime (Giessen 2013) gives some consideration to the development of global institutional influences on forest management across the planet.

Ulrich Beck has similarly observed that the nation state has limited value as a unit for understanding society in the world today (see for example Beck 2005a). He argues that citizens are faced with a range of challenges that are global in scope. There has emerged a 'global domestic politics' (Beck 2005b), a form of politics that does not address the 'zombie' nation state as the old epicentre of political power, but one in which other sources of power are involved in the creation of challenges that are understood and addressed globally, or at least transnationally. He argues for a new 'cosmopolitanism', both as an emergent property of global political and power systems and as a necessary paradigmatic turn in social science analysis.

It is within this global perspective that the theorised transition of wood production is analysed here. It seeks to understand a process that is replicated across the globe and has also been conducted in, and influenced by, global systems of trade, governance, institutions and technology, as well as the global biophysical systems. As Wackernagel et al. (2004, p. 273) note, global analysis benefits from being '… straightforward, because the Earth as a whole has no foreign trade. But analyses of lower spatial levels are more difficult to interpret'. Conversely, global systems entail a number of limitations on analysis. For instance, data collated at global levels can have significant limitations. Observations and conclusions based on global summaries can also fail to appreciate real regional, national and local differences.

While a larger portion of the world's wood is produced and consumed within national boundaries, international trade has a significant impact on price, production and policy within these countries. Further, global power is influenced by numerous other factors, such as international treaties, the activities of non-government organisations, international third party certification and globally organised capital in the form of transnational corporations. These trans- and supra-national influences are vital to the understanding of global processes, but also critical to understanding the peculiarities of national or local situations. The reach of global processes is never far away and, thus, a critical consideration for all with an interest in wood production and forest management.

While this analysis seeks a global understanding, then, three case studies have been chosen and approached at a national level, which is where the greater wealth of data is available. The chosen case studies nations contain a diversity of positions on the spectrum of the proposed wood production transition being studied. They include both developed and developing countries. In addition, Australia and Indonesia, both large countries, contain separate jurisdictions and regions at varying stages of the transition process within each country. The case studies involve in-depth engagement with various data sources describing the transition in wood production and forest use in each country.

1.4 Nature, forests, and wood cultivation: definitions

Forests and trees (as wood sources) occur with a broad spectrum of characteristics across the globe. This presents real definitional challenges (Batra and Pirard 2015). Because of this Batra and Pirard stress the need for creating definitions that are fit-for-purpose. For this thesis, there needs to a be a clear distinction between *natural* and *non-natural* forest types As part of that needed clarity, it is important to consider the distinctions between different wood sources.

What is meant by *natural*? Joseph Pitt (2011) observes that the terms *natural* and *artificial* are problematic, with the distinction itself 'contrived'. Much that we label *natural* is influenced in some way by human agency, while the artifices of humanity have entirely arisen from within nature. Pitt (2011, p. 82) suggests that 'we should finally give up that worn out old distinction between the natural and the artificial'. Hodgson (1993, p. 34) concurs, noting that 'the Cartesian and Newtonian world-views have sanctioned habits of thought which involve an ultimately untenable conceptual division between humankind and the remainder of the natural world'. Yet forests and wood sources differ, and these distinctions are important. Central to the questions of this thesis is the *natural* or *cultural* qualities of forests and wood sources.

For labelling different forests, the conceptual opposite to natural, *cultural (*or *artificial),* is not generally used, but rather *plantation* and *planted forest*, referring to a planting of trees for wood production or other purposes. The suggestion of Hay (2002) is useful here—that we distinguish between natural and cultural *processes* rather than *states.* The use of the verb *plant* as root word above points to the important distinction being the *process* of how a forest is established. However, as will be explained in more detail later, many forests that are considered to be natural have had significant human influence in their development. Fire, as well as other hunting and gathering and semi agricultural processes of forest disturbance, undertaken in order to encourage the proliferation of preferred species for food and other uses, have all influenced the nature and structure of forests. Because of this, the present condition of those forests cannot easily be said to be purely *natural* (in the sense of being somehow free of human affects).

However, there are qualities to forests that can be distinguished as *natural* that describe key features which different forests have to a lesser or greater extent. For this work the key quality defining naturalness is the presence of an ecosystem containing a complex suite of species that are largely indigenous to the area and whose presence in that locale can be largely attributed to processes other than human intervention. For further refinement it might also be useful to consider that the trees that dominate the forest are primarily the result of natural regeneration, or that human processes of disturbance have nevertheless maintained the forest ecosystem with its suite of primarily indigene species. By using this definition of *natural forest* the word *natural* becomes a label to describe a certain condition or type of forest. This leads to consideration of other forest types—'non-natural' or artificial forests. These are not generally described as such in the literature—rather, as we have seen, the most common terms used are *plantation* and *planted forest*. So the next definitional issue that needs to be tackled here is defining the various sources of wood, recognising that not all wood comes from *natural forest* as defined above.

This problem has had some attention in the past decade. Carle and Holmgren (2003) undertook a review of definitions employed in international forest and forest product data collection and analysis. This led to the development of a spectrum description of naturalness and management intensity in forests. They used the term *planted forest*, which includes forests described as *plantation*, as well as the more intensively planted subset of *semi-natural* forests called *planted semi-natural* (see also Kanninen 2010; Penna 2010). The reality is that these wood sources occur on a spectrum with no neat dividing line, especially when analysed at the global scale. The definitions developed (Figure 2) have been adopted in international forestry discourse and will be useful in this work.

<table>
<tr><th colspan="4">Natural forest wood</th><th colspan="2">Cultivated Wood</th></tr>
<tr><td colspan="2">Natural
Essentially naturally regenerated</td><td colspan="2">Semi-natural
Intensive silvicultural assistance in regeneration of primarily native species</td><td rowspan="2">Plantation
Primarily introduced species</td><td rowspan="2">Trees outside forests</td></tr>
<tr><td>Primary</td><td>Modified</td><td>Assisted natural regeneration</td><td>Planted</td></tr>
<tr><td>No clearly visible signs of human activity.</td><td>Clearly visible signs of human activity.</td><td>Activities such as weeding, fertilizing, thinning and selective logging</td><td>As for Assisted but also includes planting, seeding and coppicing of specific species</td><td>Planting of species for afforestation or reforestation, often as monoculture</td><td>Stands smaller than 0.5 ha in agricultural and urban landscapes</td></tr>
<tr><td colspan="4">Forest</td><td colspan="2">Non-Forest</td></tr>
</table>

Figure 2. Continuum of wood source qualities (modified from Carle and Holmgren 2003).

Using the above spectrum allows a more careful siting of the basic duality examined in this thesis—shifts in wood sourcing between natural forests and cultivated wood sources. A distinction is made between two main categories of wood sources. These are *natural forest wood* as defined already, and *cultivated wood*. The latter term is used to include plantations, agroforestry and rural and urban tree plantings, that is, trees planted with wood cultivation being the primary or a potential reason for their eventual use. The key determinant is that the trees were intentionally planted by humans for productive purposes. This expands on the widely used dichotomy of *natural forest* and *plantation* (for example Ajani 2011b; Brown 2000; Sedjo 2001) by including the role of trees outside forests (FAO [Food and Agriculture Organisation of the United Nations] 2010a). The definition of *forest* itself is also fraught. However, using the term *wood cultivation* for the activity of growing the wood and *cultivated wood* for the planted trees and resultant wood, allows some circumvention of the debate about whether trees grown as essentially short rotation fibre crops using largely agricultural models of production (namely, plantations) should be considered as forests (Sasaki and Putz 2009; World Rainforest Movement 2003). It recognises that 'trees and forests are not synonymous' (Long and Nair 1999, p. 146), and that trees outside forests are a growing and significant source of wood. For the purposes of this thesis, it will suffice to recognise that there are forests (landscape dominated by trees), non-forests, and a zone of intergrading.

Distinguishing between natural forests and wood cultivation zones also has implications for the terminology of relevant land management. *Cultivated wood* might better sit within agriculture rather than forestry. This research will generally refer to the activity of *wood production* (covering the full range of wood sources) or *wood cultivation* (covering wood sources not from natural forests) rather than *forestry* when the discussion is focused on generating wood. *Forestry*, will be used to describe the institutions (in the sociological sense of the word) that have developed around managing forests and wood production. Importantly, *wood cultivation* and *cultivated wood* more clearly describe the production of wood than *forestry*. This is because *forestry* runs into some limitations in relation to wood production from sources that are outside *forests* and for when forests are managed for purposes other than for wood production.

Part 2: Transitions in forest use and wood sourcing

2 An environmental history of forest use and wood sourcing

> *No nation ever began to look for fuel underground till their woods were gone* (Bishop of Llandaff quoted in Watson 1817, p. 175).

The relationship between humanity and forests is a key theme in the evolution of our species. The development of tools such as fire, axe and livestock husbandry has had a profound impact on the forests of the world. The drive to use forests for wood (and other uses) has been a key driver of the ebb and flow of humanity and forests across the planet. 'All human societies, everywhere, throughout history, have existed within and depend upon biotic communities' (Hughes 2006, p. 14)—humanity's relationship with forests and wood is woven inseparably into the natural world within which humans exist.

The natural resource endowment of standing forests that many societies have used for wood production has been a key dimension in the political economy of wood production. Factors such as land costs, forest management and resource establishment are not a consideration when the resource primarily comes from the taking of wood that has grown through natural regeneration, whether from local forests or from access to more distant forests, perhaps through colonisation and conquest. As these processes of exploitation, expansion and conquest reach their limits and the endowment exhausts, alternatives are sought—particularly through various forms of stewardship of forests and the cultivation of wood. This process is considered here. In order to reach a fruitful understanding of the current state of evolution in the global use of wood and forests the historical context needs to be reviewed; thus mandating a global environmental history of wood and forests.

As a first step in this review consideration is given to a suitable thematic structure. Four approaches are reviewed here briefly. They are not meant to be comprehensive but simply represent a diversity of approaches. They provide some guidance as to a suitable thematic for structuring an environmental history of wood and its sources. In structuring his environmental history, Simmons (2008) uses the theme of the dominant form of energy as a key marker. He identifies four broad historical phases around primary energy sources: the gatherer-hunter[4] phase, the more intensive collection of solar energy use through cultivated crops, pasture, wind and wood fuel starting around 10,000 years ago, the period from 1750 to 1950 in which an industrial society dominated through the opportunities supplied by fossil fuels, and finally the period 1950 to the end of the millennium in which fossil fuels, but also other energy forms, combined with rapidly expanding global information exchanges to create the post-industrial era. This approach has relevance to an environmental history of wood, as a significant portion of historical wood use has been for energy.

For a different approach, a recent economic treatise (Hyde 2012) uses the role of marginal economic activity to describe a Von Thunenian[5] model of change in wood production from forests. Hyde delineates three stages of forest use. The first is the New Forest Frontier, this being forestry conducted as a land clearing activity to create agricultural land, with the wood itself essentially free. This stage has two distinct subsets, one being that of shifting cultivators moving

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[4] The term *hunter-gatherer* for societies that sustained themselves from foraging for food (non or pre agricultural) has been contested (Lee 1992). Here I have used *gatherer-hunter* instead in a nod to the complexity behind the terms and to recognise the gender biases implicit in the terms.

[5] The basic Von Thunen model proposes that distance from a central market and the transport costs for goods to that central market determine the surrounding pattern of land use (Nelson 2002).

through the landscape on a cyclic pattern and the other permanent settlements with a shifting frontier. The second stage, Developing Forest Frontier, occurs when the marginal cost of clearing more agricultural land becomes higher than the benefits. However, demand for wood is such that the frontier extends now by the logging of forests, without clearing the land as an objective. Whereas agriculture led wood extraction in the previous stage, now agricultural expansion might (or might not) follow the expansion of logging into the frontier. The third stage, the Mature Forest Frontier, occurs when the marginal cost of producing wood through sustainable forest management, plantation establishment and trees outside forests that are located closer to the centres of settlement, equals or is less than the cost of exploiting the receding natural forest frontier.

Finally, two historical case study approaches to the evolution of forestry are reviewed as they outline a perspective focused specifically on the use of forests for wood extraction. First is the work of Lane and McDonald (2002), who hypothesise stages in the evolution of forest management, largely based on Australian, Canadian and United States analysis. They suggest five stages: '(i) traditional gatherer-hunter society, (ii) exploitive colonisation, settlement and commercialisation, (iii) wood resource protection, (iv) multiple-use management, and finally, (v) sustainable forest management or ecosystem management'. They propose these stages as a 'general model of forest management through time' (2002, p. 193). In a similar vein, Kimmins (2002, p. 265) outlines five phases in the evolution of forestry: a preindustrial low level sustainable exploitation, a non-sustainable exploitation phase as populations grow, the commencement of 'administrative forestry', an ecologically based forestry (wood biased however), and then, 'social forestry—ecologically based, multi-value ecosystem management'. In relation to this thesis the limitation of these two approaches is that they are both grounded in the discipline of forestry and the logic of wood production as an integral part of forests and forest management. They seek to explain how people (including foresters) have responded to changing demands for wood production and its conflict with other demands from forests. In as much as this thesis seeks to explain a transition from natural (and extensive) forest wood sourcing to intensive wood cultivation it is possible that this logic of the wood/forest nexus will not serve to fully explain the transition. For this reason a thematic structure has been developed that hybridises the above and incorporates a unique parallel post-forestry thematic. It should be noted that the themes are generally reviewed as chronologically sequential. But in reality different places have been at different stages (or themes) at the same point of time. The six themes proposed are:

1) a) **Forest utilisation—Pre-agricultural**

   b) **Forest utilisation—Agricultural**

2) a) **Stewardship forestry—Wood primacy**

   b) **Stewardship forestry—Balance and multi-use**

3) a) **Post forestry—Wood cultivation**

   b) **Post forestry—Ecosystem service provision**

The first two themes of forest utilisation relate to a largely opportunistic utilisation of forests arising from their presence in the home range of pre-agricultural peoples and expanding agricultural populations. Here, wood is sourced from essentially wild sources. The second two stages of stewardship forestry involve the emergence of institutional arrangements to manage forests and their wood production—the beginning of sustainability. The last two are labelled post-forestry. They are distinguished from the previous two sets of themes in that they are spatially, rather than temporally distinguished. That is, they occur simultaneously in separate locations rather than sequentially in the same location. Figure 3 gives an outline of the four different approaches and the synthesised thematic outline to be used (note that while they are presented as distinctive periods for the purposes of delineating a workable thematic their sequencing in reality was obviously more intergraded). It shows how they relate to each other.

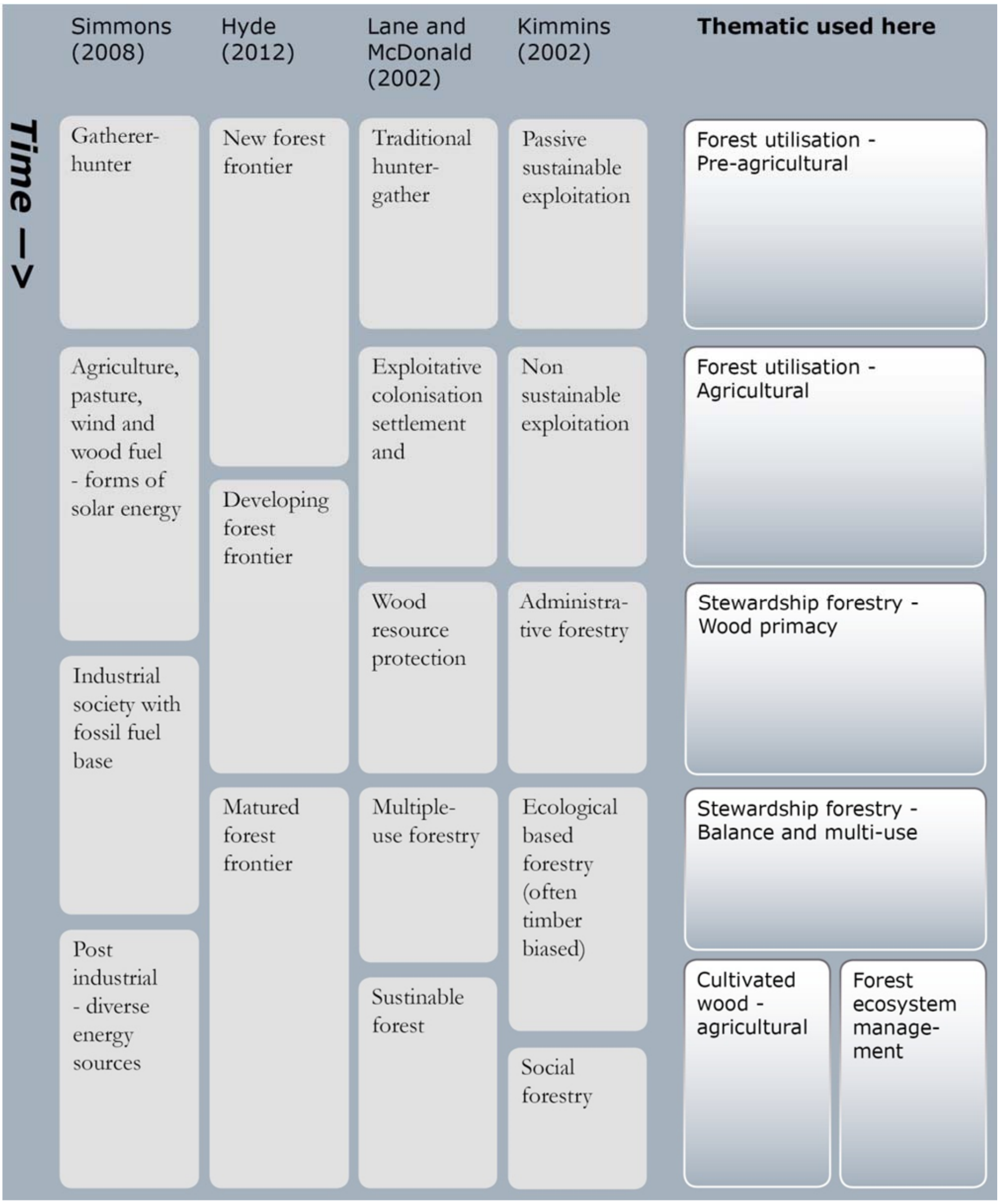

Figure 3. Outline of main thematic forest and forestry environmental histories reviewed and the revised thematic used here.

2.1 Forest utilisation—pre-agricultural

Almost all the natural forests of the world have a history or prehistory of human interaction. Simmons (2008, p. 45) notes that the advent of agriculture, or the arrival of 'first contact' colonising modern societies, was not the beginning of human interaction and alteration of nature (or forests). Similarly, Wiersum (1997) identifies a long history of humans manipulating forests for their own benefit. This includes modifying forests with disturbance to encourage certain plant and animal species (Hladik et al. 1993), a practice that had been going on for millennia. Indeed, it is possible that early phases of human-created deforestation altered not just the places within the widespread footprint of hominids, but the carbon cycle of the planet itself (Ruddiman 2012). There are examples of fire management by gatherer-hunters in upland England and Wales, Australia and the moist tropical forests of Latin America, including the Amazon basin where humans altered the biophysical nature of forests (Simmons 2008).

Swidden[6] styles of agriculture have been considered to occupy a transition point between gatherer-hunter and agricultural phases (for example, Bailey et al. 1989). The clearing of small areas in forests has possibly occurred on a spectrum from small clearings to encourage preferred browsing fauna and pioneering flora to clearing for deliberately planted crops and holding of domesticated animals. Importantly, Bailey et al. (1989) point to the early emergence of competition between forests as sources of wood and other wild foods, and the use of the land cleared of forest. Simmons notes early forms of agriculture based around small forest clearings were an important part of human interaction with the forests. Specifically focusing on this form of interaction with the forests of South America he notes; '…given many centuries of occupation by gatherer-hunters followed by horticulture and farming, the possibility exists that the Amazon of

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6 Swidden is a term used to describe a shifting agricultural development involving clearing of vegetation through fire and cutting, planting and subsequent abandonment of the fields as site productivity decreases. It is widely practiced in the uplands of Southeast Asia, but also parts of the Americas and Pacific. See Mertz et al. (2009) for details.

today's environmental concern is mostly a product of 300 years of depopulation since European incursions (Simmons 2008, p. 34).

Weaving through the evidence of changes in forests wrought by gatherer-hunter peoples and emerging agricultural societies was the effect of the changing global climate. In particular, away from the tropics the ending of the last ice age 12,000 years ago and the recession of the icesheets and warming climates saw the march of forests north across the higher latitudes of the northern hemisphere (for example Williams 2002, pp. 7-11, although he contends that this might reflect a lack of research effort in the tropics). This occurred simultaneously with the shift of humans into these areas. In the tropics it seems likely that humans simply did not live in tropical rainforest prior to the development of agriculture. Bailey et al. (1989) found that evidence generally supports the idea that the world's tropical rainforests never supported pure gatherer-hunter populations, but, rather, people in these environments always maintained some level of trading with outsiders, as well as simple swidden-type agricultural activity. They also suggest that most of the world's tropical rainforest areas exist at a greater extent now than was the case in earlier periods. In addition, the existence of humans there now is the result of adaptation by peoples to expanding rainforest regions following the rising warmth and humidity after the last ice age, rather than incursion into existing forests by newcomers.

While much of the evidence of early impacts on forests by the arrival of gatherer-hunters is buried deep in prehistory, one example is quite recent and consequently relatively well known. The arrival of Maoris in New Zealand a mere 1,100 years ago had profound effects on the landscape of those large islands. They arrived as a gatherer-hunter community and proceeded to make vast and dramatic changes to the forests of New Zealand. In little over two hundred years 8,000—12,000 people on the South Island destroyed more than 3.2

million hectares of forest, mostly through the direct and indirect effects of fire (Williams 2002, p. 21). To put this into context, the Australian island of Tasmania on the opposite side of the Tasman Sea from New Zealand is thought to have lost 1,700,000 ha of its natural forest in the first 200 years of European settlement[7]. In effect, a modern, industrial, western frontier society with several times the population density of the south island of New Zealand had a smaller impact on its forests than that much smaller group of gatherer-hunters over a similar time period.

There is strong evidence that natural forests throughout the world have developed and evolved into their current forms in response to human interaction. Simmons refers to 'near-natural forests' (2008, p. 34). In looking to describe and understand the evolution of wood production from natural forest extraction to wood cultivation this is important. While the differences between natural forests and plantations might seem immediately obvious, the assumptions behind that difference demand considered thought.

2.2 Forest utilisation—agricultural

> *Over the last 10,000 years the spread of farming has almost matched the earlier spread of the use of fire and of language [in extent]. In all three cases, at one point in time no people had the new technology. Then some people used it, while others did not, and those who had it enjoyed great advantages against those without it. Eventually in the cases of fire and language, all people used it. This point may yet come with respect to agriculture, although to this day in the Arctic, and in several moist tropical forests, people survive who neither practice agriculture themselves nor eat its products. They now account for less than 1 per cent of humankind—and less every day* (McNeill and Mauldin 2012, p. 9).

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[7] Based on the 1750 estimated extent of 4,822,000 ha and the 2005 extent of natural forests from *Sustainability Indicators for Tasmanian Forests 2001-2006* (Tasmanian and Australian Governments 2007).

Wood was the first and primary fuel source for the communities that emerged from the development of agriculture. It was also often a critical material for shelter and tools. The importance of wood and its resulting overexploitation led in turn to subsequent expansionary warfare to control wood resources further afield (Simmons 2008; Vogt et al. 2007). Wood, and the forest that provides it, has been a significant historical driver in the waxing and waning of societies, and the struggles between them. The Greek historian Thucydides noted the Athenians' alarm at the loss of their northern colony of Amphipolis to the Spartans for, among other reasons, 'the place was … useful because it supplied timber for ship-building' (Thucydides 1972, p. 329).

A feature of this period was the burgeoning of human populations that the increased productivity of agricultural food production made possible (Simmons 2008). Whereas wood was not known to have been a limited resource for previous populations (food generally was much more limiting) agriculture changed this. Suddenly agricultural societies, with their greatly expanded food production and populations, began to confront localised limits to wood supplies. Nevertheless, this forest use can still be characterised as 'pre-forestry' wherein 'exploitation is simply the use of a forest resource without any explicit management activity to promote or ensure the renewal of desired values' (Kimmins 2002, p. 264).

In the classical period forest use for wood probably played second fiddle to the impact of agricultural clearance. Williams (2002, pp. 79-80) suggests this was the primary cause of forest change. He ventures the impact of clearance and subsequent agriculture and use of domesticated stock had a much greater impact on the forests than the writings of the time indicate, with their emphasis on the impacts of ship building, metal smelting and supplying fuel and construction wood for new and growing cities. He argues that this is a result of forest impacts being subsumed into the tasks of agriculture and often being the work of slaves—thereby getting little attention in the historical record.

As agricultural societies grew in size and complexity, so too did maritime trade, developing in the Mediterranean in the last millennia BC (Williams 2002, p. 85). The development of silver for currency, the use of slave labour, and the joining together of disparate regions by the ability to transport bulky materials over large distances by ship, spawned an emergent centre of maritime trade—a harbinger of the global blossoming of the use of ships and seas to connect agricultural societies over the next two millennia. This was also the period in which the religions that shaped the coming industrial period developed. In his now classic essay, 'The Historical Roots of our Ecologic Crisis', White (1967) lays the blame for the world's environmental degradation at the feet of Western Christianity. Williams (2002, pp. 165-6) observes that White's thesis is sorely undermined by evidence of extensive deforestation efforts by, for example, Greek, Roman, indigenous American, Polynesian and Chinese societies. From Williams' perspective, forest degradation is essentially human in origin.

A question that arises here is why did the shift from gatherer-hunting to agriculture occur such a long time ago in human history, whilst the shift in wood collection from natural forest exploitation to wood cultivation is still only now underway? Indeed, as history is often imagined, this change from gathering and hunting from wild ecosystems, to farming, was at the very beginning of human history. But in the greater journey of 150,000 years of modern human presence on the planet, the shift to farming really only took place a mere 10,000 years ago (McNeill and Mauldin 2012; Simmons 2008). From this viewpoint the shift has occurred within the few short millennia in which we 'became an increasingly important force in shaping the global environment' (McNeill and Mauldin 2012, p. 3).

Sutton (1999) conducts a 'back of envelope' estimate of the area of forest needed to meet gatherer-hunter food and wood needs—c. 100 ha per person for food versus 0.2 ha per person for wood. He suggests that this clearly created pressures and incentives to develop agriculture much earlier than the cultivation of trees for wood. The far greater capacity of wild systems to meet wood needs meant that the incentives to develop wood cultivation came much later than they did for terrestrial food sources (although fisheries, like wood, are only now witnessing the transition away from wild caught sources).

2.3 Stewardship forestry—wood resource sustainability

It was in Europe that the principles of stewardship forestry that would be carried forward into the world system emerged. However, before these are looked at in more detail it is useful to first recognise that the development of stewardship forestry had occurred elsewhere and in earlier times. In addition, there is a need to establish what is meant by *stewardship forestry*. A regime of stewardship forestry is likely to emerge when it is recognised that natural forests are utilised at a rate that is unsustainable and that some forms of management and restriction are required in order to prevent the wood resource running out. This can take the form of planting trees in order to provide future sources of wood but also the exertion of control over existing forests to prevent wood being taken at a rate that is unsustainable.

There are numerous examples of this occurring prior to the emergence of the 'scientific forestry' of the modern era. Possibly the earliest records of stewardship approaches to forest usage area are to be found in the Chou Empire of China (c. 1100-256 BC). This was where the Emperor dictated that a forest service be established to look after existing forests and undertake reforestation (Hermann 1976). It is also possible that earlier and even pre-agricultural societies developed taboos and cultural practices that limited or controlled the taking of certain wood or the disturbance of particular forests.

In medieval Europe the use of forests for wood was largely approached through systems of rights assigned by royalty and church that allowed access for procurement of wood and related materials. Extracting resources was widely allowed under these rights, except for hunting, which the nobility kept to themselves (Williams 2002). From this approach grew some of the earliest records of forest regulation—regulation that grew from an emerging sense that the forests were limited and had values worthy of protection. Population increases, along with an increasing concern that the 'frontier' could not expand into the forests forever, led to the development of royal charters and ordinances from the late thirteenth to middle fourteenth centuries (Williams 2002, pp. 130-7). Ironically, this period of concern about forest over-exploitation was ended by the plague, which killed over a third of the population of Western Europe over several years around 1350. There was a dramatic retreat of population from the margins due to weather deterioration and the war and pillage that followed into the fifteenth century—'[f]or a while, the forest had been reprieved' (Williams 2002, p. 136).

The stewardship forestry approach, which would eventually spread across the globe, emerged as European rulers increasingly recognised a growing crisis in forest depletion. This was brought on by the large volumes of wood used for fuel and the growth in wood demand for building and shipping. It led, for example, to the enactment of laws such as the French Forest Ordinance of 1669 (Hughes 2006, p. 107). Similarly, in the eighteenth century in Germany forest loss became increasingly apparent and a government concern. This was a time when the modern profession of forester emerged and 'forest management' for wood production started. Wilhelm Gottfried von Moser published the influential text, *Principles of Forest-Economy,* in 1757. These early approaches to forest management in Europe were much more akin to the forest management approach known as 'plantations' in the twentieth century with their emphasis on standard species, planted rows and monocultures with ongoing yields (Simmons 2008). Importantly, the development of this technocratic forest management, steeped in modernity, would spread across the globe and be adapted and applied to natural forests in the colonial periphery. This is a critical point for this thesis, focused as it is on the shift of wood production from natural forests to cultivated wood sources. In a sense, the modern stewardship forestry institutions were first based on cultivated wood sources—the replanted forests of Europe. Only later were they then applied to the natural forests of the colonised periphery.

The forestry that emerged in Germany had strong patriotic aspects to its practice (Schama 1995). Its spread, with the rise of the notion of the nation state, is consistent with the broader pattern of western ideas emerging from Europe at the time. Giddens (1990, p. 73) notes that the sovereignty that is essential to the modern nation state 'is linked to the replacement of "frontiers" by "borders"'. For wood/forest socio-ecological systems this would push the shift to the stewardship forestry basin and integrate it into the modernising of the world. The frontier was always a point at which expansion was possible; but a border has no such potential. A new way and new logic is required. A society that operates within frontiers can push against these in a way that it cannot when it is contained by a boundary with another nation state. It follows that there is an overlap with the development of the nation state and stewardship forestry, as the logic of frontier expansion is replaced with the logic of living within boundaries. The latter requires a management of a contained (and therefore limited) resource – the logic of stewardship forestry and its pursuit of sustainability.

In fitting with the rise of the nation state, German foresters were particularly influential in spreading stewardship forestry ideas throughout the world during the next two centuries (Simmons 2008, pp. 125-6). The first Inspector General for forests in British India was a German, Sir Dietrich Brandis (Advani cited in Saldanha 1996). Along with another senior forester of German decent, Berthold Ribbentrop, Brandis was influential in the development of American forestry. He provided collegial support, advice and mentorship to the three key foresters who would oversee the establishment of the vast US public forest estate and its accompanying bureaucracy: Franklin Houghes, Charles Sargent and Gifford Pinchot (Barton 2002). This process was replicated in other parts of the expanding European influenced modernisation and industrialisation of the world system.

A natural limitation of any historic thematic scheme such as this is explaining the boundaries and transitions between the themes. Industrialisation did not appear overnight after millennia of undifferentiated agricultural systems. The evolution of industrialisation, generally considered to have started in the eighteenth century, followed several centuries of European expansion, in particular through the emergence of new technologies in shipping and weaponry and as a response to major social and cultural upheavals. World systems theorists place the emergence of the global capitalist economic system at around the middle of the last millennia (Engel-Di Mauro 2009). This culminated in the Industrial Revolution. This was important for the story of wood production because of the emergence of shipping as a means for globalised interaction and the shift to fossil fuels as an energy source (Simmons 2008).

Fossil fuel use in the United Kingdom rose from its first utilisation before 1600 to one third of energy output by the end of the century (Williams 2002, pp. 184-6). From about 1670, this boom in fossil fuel use lessened the concerns about wood shortage that had featured so strongly in the early decades of the seventeenth century. The German economist Werner Sombart argued that the drop in wood supply arising from the loss of European forest and the subsequent wave of coal-based innovation was the basis for the development of capitalism in the nineteenth century (Sombart 1913, cited in Reinert and Reinert 2006, p. 72). Industrialisation and the concurrent rise of capitalism as an organising force for expanding and developing society have had major implications for wood production and forest use beyond Europe.

From its beginnings in Britain, industrialisation spread to West Europe, the United States, Russia and Japan, and thence to most of the world. It spurred a massive increase in wealth, population growth and resource consumption. With improvements in shipping and processing, the demand for wood was no longer confined to the environs of urban centres or industrial heartlands, but was internationalised. The industrial 'core' commenced drawing wood from the world's forests to meet its needs. As manufacturing industrialised, the less developed world's share of manufacturing fell from 73 per cent in 1750 to just 6.5 per cent in 1953 (Williams 2002, p. 246). Thus, manufacturing outputs of newly industrialised countries replaced those of less developed countries which, in turn, had to pay for manufactured goods with the export of primary produce. Among other things, this meant wood from forests and agricultural produce from land cleared of forests. The development of industrialisation was a key factor in the development of the world system of forest use.

Vogt et al. (2007) identify three main uses of wood; fuel, paper products and industrial wood products, with two key trends noted in relation to this. Firstly, nations use a significant portion of their wood as fuel until they become industrialised; and secondly, as countries become more industrialised they shift fuel sourcing from wood to fossil fuels. Vogt et al. also suggest that with industrialisation and energy from fossil fuels, more wood is freed up for consumption in timber and paper products. Put another way, when societies industrialise, wood use shifts from being primarily a source of fuel to being a source of wood for paper and timber. Indonesia provides a case in point (Figure 4). Its consumption of fuelwood has declined significantly over the period from 1961 while industrial roundwood use (paper and timber applications) has grown.

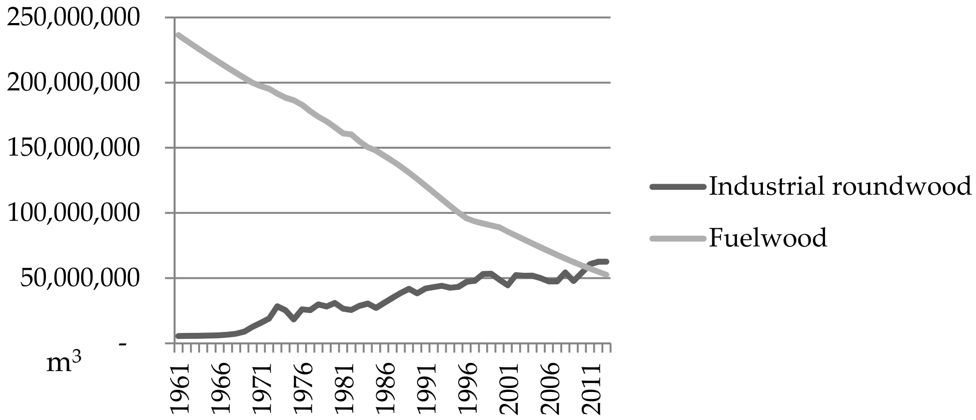

Figure 4. Indonesia's total industrial roundwood and fuelwood consumption (m^3) (FAOSTAT 2014)

Another significant feature of industrialisation's impact on wood use has been the rise of cities. Simmons (2008, p. 11) suggests that about 85 per cent of the infrastructure of cities consists of mined products. This points to a key driver in lowering wood demand—the dramatic urbanisation of the world's population. There were cataclysmic fires in emerging urban areas built extensively of wood, such as those in London, Copenhagen and Tokyo in the fifteenth and sixteenth centuries. This helped shift city building to more durable and fire resistant materials. There is some evidence to suggest that cities are more resource efficient, per capita, than rural areas (Dodman 2009; Newman 2006). If city living has been less wood consumptive than rural living, it may be that the trend to increasing urban populations will also contribute to reducing per capita wood use.[8] Cities have also most likely contributed to the development of fossil fuel usage. City expansion in the period before fossil fuel use was probably dependent on (and limited by) availability of wood for fuel. Simmons (2008) notes that transporting wood for fuel was a costly undertaking and contributed to high wood fuel prices in early cities. These high prices in turn would have provided incentive for the development of fossil fuel sources. In this sense, the development of fossil fuel use in the industrial period could be seen to have 'saved' forests from a much higher demand for wood. The demand for wood for heating, energy and cooking would otherwise have grown rapidly with increased population densities (or, conversely, it could have become a brake on growth).

Overall, then, industrialisation has had a number of major impacts on wood production and forests. On the one hand it has seen the rate of deforestation and forest degradation from wood extraction grow, initially around the new centres of industrialisation and then across the globe as the global economic system accessed the periphery for wood. Industrialisation and related new technologies in health and food production induced massive population growth as well as dramatic increases in per capita wealth that have raised demand for wood. Though this had extensive negative impacts on the world's forests, two aspects

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[8] Recent innovations in use of wood in multistorey buildings could potentially be an emerging counter trend, although at this stage there is no indication that it is likely to grow into a significant additional source of wood demand. There is also some interest in the use of wood for biofuels and other new applications. It is not clear, though, whether these are driven by demand for the wood-sourced product or by wood producers attempting to develop new markets for a surplus of wood.

of industrialisation have conversely worked to lessen demand for wood. First, the development of fossil fuels as an energy source substituted large portions of the demand for wood. Second, the development of cities (mandated by industrialisation and made possible by extensive use of fossil fuels) has led to forms of living that require a smaller per capita wood demand than more dispersed rural living. Finally, shifts in population, land use, and levels and distribution of wealth have allowed forests in some parts of the world around early centres of industrialisation to regenerate. In this period of industrialisation a shift began to occur in wood production—from the opportunistic exploitation of standing natural forest with little or no management to the development of stewardship forestry (with its earliest roots in Europe) and the emergence of the cultivation of trees for wood (Vogt et al. 2007, pp. 26-7).

As mentioned above, the history of the stewardship model of forestry is intertwined with its scientific, capitalist and colonial contexts. This saw the stewardship forestry model promoted and adopted throughout the European sphere of influence. The nexus with colonialism led to dispossession of indigenous peoples by colonial powers with forestry being brought to the service of territorial control (Bryant 2002; Saldanha 1996), even though this was often in the name of sustainability, preservation and water and climate benefits. In many places traditional communal control of forests shifted to state control. This has been called the 'Tragedies of the Invasions' (Brightman 1987, pp. 133-4). Ghosh (2007, p. 63) laments that from 'the very ancient days Indian people lived with the forests and their interaction with forests did not do any harm to the environment'. Post-colonial analyses such as these illuminate the extent to which colonial and capitalist power relations co-opted stewardship forestry institutions to their agenda.

This development of scientific forestry also dovetailed with the expansion of western capitalism. 'At a deeper epistemic level the language of scientific forestry worked to justify the shift towards commercial working' (Guha 2000, p. 60). The approach that was first developed in this European model was one focused on the production of wood and tree plantings of species optimised for wood production. Stewardship forestry arose in this context. This utilitarian approach to wood production in forests set the scene for stewardship forestry's eventual struggle with emerging demands for non-wood values from forests. In particular, an approach based on the commerce of wood production in a wood cultivation setting was then imposed on natural forests that would come to be increasingly valued for a broad range of other, often conflicting, values. It is to meet this challenge that much effort in the subsequent development of the institutions of forestry has been directed.

2.4 Stewardship forestry—'balance' and multi-use

The institutions of forestry developed in response to concern about wood shortage and the need to manage forests accordingly. However, a more general social phenomenon, the development of the 'ecological impulse' that rose in response to western industrialisation (Hay 2002), was also important, shifting perceptions of forests. In the second half of the twentieth century there was a growing recognition that the world's forests were not an inexhaustible source of wood. While the realisation was not new, an emerging global perspective could see that the frontiers had been explored, the extent of the resource was known, and its limits fixed. During this time the importance of the world's forests in providing ecological services, many with global scope, became clearer. This led to a burgeoning of interest in sustainable forest management and increased regulatory application of sustainability, along with third party certification of practices increasingly used to control wood production (Vogt et al. 2007). It was in this context that stewardship forestry began to grapple with incorporating ideas of multiple values and ecological forestry into its practice. This new turn in the stewardship forestry approach found explicit expression in the *Multiple Use Sustained Yield Act of 1960* in the United States (Lane and McDonald 2002). The management of wood production forests was legally defined as being for multiple purposes. Other legislation also reinforced this need to consider a suite of non-wood values in forest management.

This approach was widely adopted by the formal institutions of forestry worldwide. It can be seen in the publications of the FAO (Food and Agriculture Organisation of the United States), which regularly reports on the extent of multiple-use forests globally. For example, the 2010 Forest Resource Assessment (FAO 2010a) reports that 24 per cent of the world's forests are designated as 'multiple use', as compared to 30 per cent that are designated primarily for 'production'.

The rise of certification in the last decades of the twentieth century represented a new form of governance (Cadman 2011). It emerged, in part, due to the failures of state and international governance to regulate the often distant impacts of global trading regimes that spanned sovereign states to the satisfaction of social movements, notably environmental and social justice movements (Bartley 2003). In part, certification governance can be seen as an extension of the stewardship forestry model. That is, it develops in order to further forest management practice where the stewardship dominated state forestry approaches reach stagnation through the co-option of capitalist governance. The 'certification wars' that have ensued are a tussle between the pull of the highest aspirations for forest care from NGOs in particular, and the timber industry, keen to maintain the status quo, but also in need of a social licence (Humphreys 2006).

It is useful to recognise that the stewardship approach also had advocates for a shift to plantation forestry, in order to conserve other values in natural forests. Edward Swain, who was significant in the early years of the development of the stewardship response in Australia, led state forest agencies, first in Queensland from 1918-1932 and then New South Wales from 1935-1942. He was a strong advocate for a model of forest management that involved the two pronged approach of 'the creation of rapid-growing, intensively managed plantations and the preservation of natural forests for the spiritual and psychological needs of modern society' (Bennett 2010, p. 325). This approach of planting highly productive plantations was widely adopted in Australian forest management policy. Successive waves of plantation development[9] have dovetailed with a growing natural forest reserve estate; although it is less clear that the policy intent was to mirror the rationale of Swain. Increasing wood production from the plantations has, indeed, displaced the output of declining natural forest harvests that has occurred, in part, as a result of increased reservation[10].

In a number of places where the stewardship approach was used for forest management (such as Australia, the Pacific North West of the US, Malaysia, Canada) much wood production was taken from first cuts that are known to have had particularly high (and therefore unsustainable) volumes available to them (Hyde 2012; Putz et al. 2012). The ability of this model to deliver effective long term multi-value forest sustainability has been challenged (Lindenmayer and Laurance 2012; Putz et al. 2012; Richardson and Peres 2016). In response, in recent decades there have been numerous attempts to find ways to harvest wood

[9] There was extensive expansion of exotic pine species plantations in Australia from the mid-1960s to late 1980s and then a focus on eucalyptus species in the 1990s and 2000s (Ajani 2007; Ferguson 2014).
[10] See Chapter 6 for a detailed description.

and reduce its impacts on non-wood values, such as retention forestry (for example Gustafsson et al. 2012). These generally involve some variation on limiting the intensity of logging operations—such as by limiting the removal of wood and maintaining certain forest structural elements in order to increase retention of ecological benefits. Nonetheless, logging that is more ecologically sensitive is also likely to increase the costs of logging through inefficient restrictions on harvest practice or a need for more dispersed harvest ranges. Sutton (1999, p. 102), in noting this dilemma, predicted that the tension would be resolved through increased use of cultivated wood. He also suggested that this would allow the remaining natural forests to be set aside for non-wood uses such as wilderness and biodiversity. For him, this made sense given the high cost of natural forest management and the conflicting demands on 'multiple-use' forest managers: 'some [demands] of which are almost incompatible' (Sutton 1999, p. 102). This approach to wood production constitutes the emergence of what is posited here as a post forestry stage of wood production—wood cultivation.

2.5 Post forestry—wood cultivation

> *'Innovations in tree growing have rendered reliance on existing natural forests increasingly unnecessary'* (Bael and Sedjo 2006, p. 5).

The shift of wood production from natural forests to cultivated wood sources has been likened to the shift of food production from natural forests to agriculture (Carle, Ball, and Del Lungo 2009; Sedjo and Lyon 1983; Sutton 1999). The transition to agriculture from gatherer-hunter has essentially underwritten many subsequent and pivotal evolutionary developments, such as the emergence of stratified societies, trading economies, information storage technologies, and the development of tools such as steel and guns (Diamond 1997). A similar evolution in relation to wood production has taken much longer to become evident but is now well underway. Just as humans learnt to cultivate plants for food, they have also learnt to cultivate trees for wood. As noted earlier, the extensive endowment of forests relative to the demand for wood has meant that widespread cultivation of wood came much later than it did for food (Binkley 2003; Sutton 1999).

There are a number of early historical references to the deliberate planting of trees (Powers 1999). *Acacia nilotica* was used in Egypt for boat building (Simmons 2008, p. 85), whilst Evans (2009) includes several examples of wood cultivation from ancient times—in the Mediterranean, the Middle East and Asia. Many of these are for trees that had uses other than wood, such as olives and frankincense. Chinese efforts, dating back to the first millennium BC, included programs of reforestation. Java has a long history of teak cultivation, with the species generally considered to have been naturalised through intentional planting for its wood—its presence was well established by the time the Dutch arrived (Pandey and Brown 2000). From the Middle Ages on, there are examples of European jurisdictions undertaking the planting of trees for wood (in Germany, England and France), initially with a focus on local species (Evans 2009). The nineteenth century saw the beginnings of more extensive plantation establishment in Europe. The focus was shifting to species that were faster growing. There was generally a favouring of conifers over broadleaf species and the increasing use of exotics, with plantings of North American and Asian species such as Douglas Fir and Japanese Larch (Evans 2009; Simmons 2008).

It is useful to recognise the overlap of the development of stewardship forestry and wood cultivation. The two approaches were developed together in parts of Europe in response to forest loss. Only later, in other parts of the world was wood cultivation developed as a more proactive response to the declining productivity of overcut natural forest estates rather than in response to complete deforestation. Additionally, in the tropics there are examples of wood cultivation arising directly from swidden approaches (Harwood 1996). Harwood notes that the long timeframes for return on effort invested, and low labour demands for tree plantations, were (and are) discouraging factors for tree planting in more populous areas. But, as wood becomes scarcer and its price increases, tree cultivation as part of a mixed agroforestry system can create long term returns to complement shorter rotation crops. This description suggests a plausible explanation for the evolution of teak cultivation in Java.

Sedjo and Lyon (1983) commented on the dramatic growth in plantation development at the end of the twentieth century. Their review of the global state of play in the early 1980s and their predictions for the coming decades were remarkable for their prescience. They noted the predominance of global wood supply from the endowment of the slow growing but extensive boreal and temperate forests of Russia, Canada, Scandinavia and the United States. At the time 70 per cent of the world's wood production was coming from temperate regions of the northern hemisphere. The tropics and southern countries played a minor role in world production and international exports of industrial wood. They then proposed that these later parts of the world would however develop a comparative advantage in growing industrial plantation wood. This would see wood production shift 'South'.

The pressure to increase yields has been noted in the analysis of a number of writers on changes in the wood products industry. Binkley (2003) notes that the process of exploiting standing volumes in natural forests causes increased scarcity which raises the costs of wood. He then outlines three countervailing factors that serve to mitigate this. Firstly, as the cost of extracting wood from one area's forests grows as a result of accessing increasingly marginal forests, wood production can shift to other regions of the world. Secondly, increasing prices for wood make the cultivation of trees more economical. Binkley notes types of stewardship activity such as wildfire suppression and methods of forcing suitable natural regeneration as a first step in the application of the stewardship approach with a tendency for them to evolve into 'sophisticated agronomic practices'(Binkley 2003, p. 2). The third factor serving to reduce costs is the development of technological advances increasing yields from cultivated trees and wood processing. This leads to increased wood product development from smaller quantities of raw log. In a similar analysis Sedjo and Botkin (1997) suggest three drivers for the transition to intensive forest management (of which plantations were a key component); rising costs associated with increasing difficulty in accessing frontier forests; technology upping the yields of planted forests and increasing social pressure to protect old growth forest.

Brown (2000) estimated that in 1995 there were 123.7 million hectares of plantation supplying 22.2 per cent of the world's industrial roundwood and 4.4 per cent of its wood fuel production (see also Del Lungo, Ball, and Carle 2006). In 2005 the FAO estimated one third of industrial roundwood production was coming from plantations in that year. In the later centuries of the second millennium, global plantation establishment rose from very low levels in Europe and Asia. The twentieth century saw it increase firstly in countries such as South Africa, the United States, New Zealand and Australia. In the last decades of the twentieth century there has been dramatic growth in developing countries (Evans 2009, pp. 5-22; Varmola et al. 2005). Findings on plantation wood supply also reflect this rise in plantation establishment. Fifty years ago almost none of the global industrial roundwood supply came from plantations. But, in the second half of the twentieth century the shift to cultivated trees as a wood source has gathered pace (Evans 2009). During the first decade of the twenty-first century the world's plantation estate grew at 2.8 million ha a year. In 2007 3 per cent of the world's forests were production plantations, but they produced more than a third of the world's industrial roundwood. Predictions for plantation wood suggest it will grow to more than 40 per cent of the world's industrial roundwood output by 2030 and as high as 75 per cent by 2050 (Kirilenko and Sedjo 2007).

Pulp and paper production has particularly been pushed to sourcing its wood from cultivated sources through technological shifts. New chemical pulping technologies, their industrialisation, and rapid economic growth led to a dramatic increase in wood demand in the twentieth century. One of the qualities of the new wood fibre products (including paper and fibreboards) was that timber quality became less important (Williams 2002, p. 423). This increased demand for wood in general but turned out to be particularly suited to plantation development. The ability of plantations to generate large volumes of fibre in close proximity to large industrial and capital intensive processing plants provided economic incentives to invest in plantations as an alternative to the much more dispersed and spatially fixed natural forest wood sources. In the late twentieth century this pattern took on a geographic expression as pulp production moved to new large mills in Asia and Latin America in a drive to reduce production costs (Lebedys and Li 2014). Highly productive plantations in these tropical and subtropical locations can produce greater volumes of wood[11] from smaller areas. This in turn reduces land needs and haulage costs across the reduced catchment area needed to supply a mill.

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11 Brown in his review of plantations internationally noted that in general, tropical plantations have higher productivity than in temperate regions. 'At present, it is rare that in-the-field mean annual increment (MAI) at harvest, for any species, exceeds 30 cubic metres per hectare. Based on current plot trial results, however, significant advances may well be achieved in the not too distant future' (Brown 2000 p. xvi).

Agroforestry planting also shows signs of rapid growth. For example, planting began for fuelwood on a large scale in Africa and Asia in the 1970s (ABARE 1999, citing Panday 1995; Hyde, Amacher, and Magrath 1996). An increasingly important dimension of global wood supply is wood from trees outside forests. The FAO calculated that this mix of cultivated trees—in agroforestry landscapes, alongside roads and canals, across farms and around villages, towns and cities—is now likely to supply most or all of the demand for fuelwood in developing parts of the world such as Africa (FAO 2001, 2010a). Another analysis estimated that two thirds of global fuelwood consumption was supplied from trees outside forests (Smeets and Faaij 2007).

In addition, in recent decades increasing use has been made of the wood from trees grown primarily for other crops, such as rubber trees, coconut and palm oil trees (Durst, Killmann, and Brown 2004). Rising prices have generated markets for the wood of trees that would once have been burnt. Combined with the low-cost labour of the developing countries in which these crops are found and new technologies for wood processing, these provide considerable new volumes of wood resource. For example, Durst, Killmann, and Brown (2004) reported that Malaysia's $2 billion furniture industry is now using rubber wood as its preferred timber, supplying 80 per cent of its raw material.

As well as sourcing wood from outside forests and making better use of trees grown for other crops, alternative fibre sources are being considered. For example, bamboo is increasingly used to develop competitive 'high-tech' substitutes for wood products. It enjoys many of the advantages wood enjoys over metal, plastic and concrete materials—that is, low carbon, 'natural' image, renewable—while often being more productive and stronger:

> *It is quickly changing its image from the "poor man's tree" to a high-tech, industrial raw material and substitute for wood. Bamboo is an increasingly*

important economic asset in poverty eradication and economic and environmental development. It has always played an important economic and cultural role across Asia. Now the use of bamboo is growing rapidly in Latin America and Africa as well. In some countries, the processing of bamboo is shifting from low-end crafts and utensils to high-end, value-added commodities such as laminated panels, boards, pulp, paper, mats, prefabricated houses, cloth and bamboo shoots (Lobovikov et al. 2007).

As well as expanding the supply of wood (and its constitutive fibres) from new sources such as bamboo, plantation palms and rubber trees, the productivity of cultivated trees is growing. Much as the productivity of agricultural food crops has shown a long term propensity towards increasing yields (Tilman 1999); so too has the productivity of cultivated trees (Nambiar 1999).

In recognition of perceived looming wood shortages from natural forest harvests in the later twentieth century there have been repeated government interventions to support early-stage development of tree cultivation[12]. This is often driven by political imperatives such as national independence and self-reliance (in the case of Australia for example, see Ajani 2007; Gerrand et al. 2003), rather than expressing any policy preference for a change in wood production methods. Nevertheless, the effect has been the same—government investment in early-stage development of wood plantation.

Significant examples of this include Brazil, Indonesia, China, Vietnam and Australia. Brazil had tax incentives operating until 1986 for plantation generation that in turn established an industry that is now growing at even higher rates (Gonçalves et al. 2013). The Indonesian government has in place a policy to develop a plantation estate of nine million hectares by 2016 (Obidzinski and Chaudhury 2009). The Chinese government is working to a target of 13.3 million

[12] See Howarth (2012) for a relevant discussion on the role of government in early-stage technology intervention in clean energy technology.

hectares of fast-growing high-yield plantations to be established between 2001 and 2015, with 45 per cent to be pulp logs (Barr and Cossalter 2004, p. 269). The State Forest Administration subsidises financing to encourage fast establishment. Ajani (2011b, p. 59) reported that by 2008 the country was on target to meet this goal, concerns about processing capacity notwithstanding. Vietnam's plantation estate grew at 5 per cent per year during the period 1990—2005 (FAO data cited in Sandewall et al. 2010, p. 567). This rapidly growing estate has moved into production over the last ten years. RISI data cited in Phuc (2011) shows Vietnamese hardwood chip exports growing from about 500,000 m^3 a year in 2003 to nearly 4,000,000 m^3 in 2010. Sandewall et al. (2010, p. 567) note that the reforestation trend in Vietnam and China in particular has been significantly driven by farmers. The shift of forest use in Vietnam to plantations in some ways reflects the Australian experience where areas initially logged and then subsequently cleared for agriculture (dairy and cropping in Australia, shifting agriculture in Vietnam) have subsequently been replaced by state-promoted plantation schemes.

Wood volumes produced per unit land area are much higher from plantations than from natural forests. A summary of published yield tables in Paquette and Messier (2009) shows a range of mean annual increment (MAI)[13] of 5-40 m^3/ha/yr for intensive monoculture plantations compared to 1-3 m^3/ha/year for intensively managed natural forests and less than 1 m^3/ha/year for certified natural forests. Recent work on Brazilian plantations indicates an average MAI for its eucalypt plantations of 40 m^3/ha/year—up from an average of over 30 m^3/ha/yr in 2000

[13] The Mean Annual Increment (MAI) is a measure of forest productivity. It is measured in units of wood grown per unit of land per year, most commonly now, meters cubed per hectare per year.

(Gonçalves et al. 2013). Häggblom (cited in Nilsson and Bull 2005, p. 10) estimated, '88 million ha of successful fast growing plantations of Brazilian type (mean annual increment 20-25 m^3/ha/year) would take care of the total supply for the global consumption of industrial hard wood in 2015'. In the period 2006-2012 Brazil established around a half a million new hectares of eucalypt plantation a year with an average MAI in the order of 40 m^3/ha/yr (Gonçalves et al. 2013).

Extensive plantation establishment initiated under government-supported programs and, often, large corporate investments, has also fuelled considerable political controversy and has sometimes led to perverse outcomes. Strong criticism has been levelled at plantations on the basis of their impacts on social and ecological values (Bowyer 2001; Casson 2004). In Indonesia, a significant portion of the land allocated for plantations since the 1990s has been cleared but not replanted. The companies involved have been using the subsidies and land allocations as a source of cheap wood in clearing the land, but then not replanting. This had the perverse outcome of a major reforestation project leading to net deforestation (Obidzinski and Chaudhury 2009, p. 83). A similar outcome occurred in the Australian state of Tasmania under a federal government tax incentive, the Managed Investment Scheme. At the height of this program Tasmania had a high rate of clearing of natural forest for conversion to plantation (Forest Practices Authority 2014). A study of plantations established across 1.4 million hectares of Sumatra found that four of the five plantation concessions assessed failed to deliver economic benefits that were more than the economic costs (Maturana 2005). This was primarily because the Indonesian government did not pass on the full cost of the forest lands handed over (largely areas of forest degraded through past logging). These examples from recent history point to some of the reasons industrial plantation programs implemented in the last 50 years have been heavily criticised. In addition, there are major social impacts implicated with the dramatic landscape and socio-economic changes associated with large scale plantation establishment (Gerber 2011).

There has also been considerable criticism of plantations over additional environmental impacts (Sawyer 1993). Among these are impacts on soil condition, water quantity and quality, chemical use, the spread of exotic species, creation of ecological 'deserts' and the loss of natural forest through conversion. In many cases the criticisms are highly site and condition dependent. In addition there can be considerable scope for changes and improvements in management practices to reduce the impacts. The literature in relation to some environmental impacts of plantations points to a swiftly expanding new practice (wood plantations) and an effective adaptive management responsive of research and adjusted practices. This is particularly so in relation to soil nutrition. Soil nutrition is potentially depleted when fast growing tree crops are regularly harvested and the biomass removed (Berthrong, Jobbágy, and Jackson 2009). Yet, there is considerable evidence that tree plantations may have the opposite effect, contributing to 'long-term improvement in soil quality and site productivity, especially on degraded soils…' (Fox 2000, p. 187), and even in examples of declining soil fertility, silvicultural practices are quickly refined such that this process is reversed (O'Hehir and Nambiar 2010). At the other end of the spectrum, issues of competing land use, conversion and deforestation of natural forests have proved much more intractable.

There is a significant biodiversity and ecosystem service cost where plantation establishment involves clearing of natural forests, either directly or through forcing food production to displace natural forests (for example Bremer and Farley 2010; Brockerhoff et al. 2008; Gibbs et al. 2010; Pawson et al. 2013). Sedjo and Botkin (1997) argue that this fails to recognise the opportunity for vastly more productive intensively managed forests to replace natural forests as a source of wood, allowing remaining natural forests to be better used for non-wood values such as biodiversity. Nonetheless, there are examples (such as in Indonesia and Australia) that clearly show that public policy has at times had the effect of plantations being established at a significant cost to natural forests.

In regard to biodiversity in plantations, Bremer and Farley (2010) found that plantations are most likely to contribute to restoration of biodiversity when established on degraded lands, rather than when replacing natural ecosystems. They noted that the environmental outcomes of plantations varied widely depending on the type of plantation and previous land uses. For example, they found that plantations utilising indigenous species had a more beneficial effect on biodiversity than those that did not[14]. Bremer and Farley also noted the importance of plantations to biodiversity conservation and recuperation at a landscape level. They found the impact on the biodiversity outcomes for plantations were negative where the plantation was established through conversion of natural forests, grasslands and shrublands. In contrast, in some cases conversion of secondary and degraded forest and exotic pasture to plantations using indigenous species could be positive.

Along with these critiques, there are also analyses that stress the considerable opportunities for utilising existing and new cultivated wood crops to deliver a wide range of ecosystem services, while supplying roundwood (see Bauhus, van der Meer, and Kanninen 2010, for a detailed treatise). Where these plantations are established on previously cleared land and have good management practices they have become positive examples of the possibilities of plantations. This is

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[14] See also Lugo (1997) for a description of the potential for tree monocultures to support the more rapid re-establishment of tree diversity in tropical sites.

important because while wood cultivation has been growing and subject to the above criticisms and demands for more positive environmental and social outcomes, such criticisms and demands reflect the rise of much higher expectations for ecosystem service delivery across the landscape. Leslie (2005) notes that while wood demand and non-wood forest product demands are static or only slightly increasing, demand for environmental services is burgeoning (but 'unmonetised'). This rise in demand is occurring as wood cultivation has taken off. Its growth is essential to understanding the evolution of wood cultivation, as well as a reappraisal of the role of natural forests in providing services other than wood.

2.6 Post forestry—ecosystem service provision

Forests have long been used for values other than wood, in particular hunting and as a source of other natural materials such as honey and gathered foods. Agricultural societies tended to develop cultures that saw forests as other; as places separate from the cleared agricultural land from which sustenance was derived. In some cases this developed into a religion-sanctioned suspicion of forests, as displayed in the ordering by a Benedictine Abbot to bless the wood cutters because '… a wild spot…is, as it were, in a state of original sin' (quoted in Leclercq 1911, p. 136). As the economic drive to clear forests for agricultural land, and to provide wood for fuel and building increased pressures on forests, a counter current in conceptions of forests developed. This saw forests as reservoirs of positive virtue and value: as places such as hunting grounds for the well to do, a symbol of wealth both of the individual and the state in general, and as links to the Garden of Eden and purity. Schama (1995) describes western civilization's fraught relationship with forests going back to classical times. This involved a schizophrenic lurching between longings for a wooded arcadia and its sylvan inhabitants, and fear of the dense forests north of the Alps and their resident barbarians.

Williams (2002, p. 166) outlines the growth of new sentiments towards forests as Europe rose to global pre-eminence. These started with utilitarian exploitation. From this, a second stage, stewardship, emerged in the face of recognition of limits to the forests and their importance. Then came what he refers to as the 'third stage'; a cherishing of beauty in forests. This later stage was likely to include a growing cohort seeking outdoor recreation opportunities away from the cities they increasingly inhabited. This group had an entirely different set of expectations of forests as affluence and recreational time spread from the upper classes through to the middle and working classes (Simmons 2008, p. 127).

As part of changes in how people have valued forests there has been an increasing recognition of the role of other ecosystem services supplied by forests, particularly biodiversity, water and carbon services. These, in turn, have become part of the political-economic dynamic shaping the transition of wood production away from natural forests to cultivated trees. Using forests for wood production has been one of the most conflict-riven natural resource issues (Lindenmayer and Laurance 2012). Questions of the ecological impacts and sustainability of natural forest logging have been widely researched, although, Lindenmayer and Laurance (2012) argue there is a widespread use of poorly executed studies. In particular they note the small scale of the temporal and spatial parameters often used and the problems associated with 'shifting baselines'. Given this, they caution against the often simplistic assertions made, particularly, by organisations and researchers asserting a pro-logging case. Wood extraction can have significant impacts on ecological values. The impacts are greatest when the wood is harvested in a way that is quite different to natural forest disturbance processes and/or that reduces complexity in the resulting forest (Gustafsson et al. 2012, p. 633). Thompson et al. (2011) note that when ecosystems such as forests are managed for wood only then other ecosystem services tend to get less attention.

Gustafsson et al. (2012, p. 633) make the claim that; '[m]ost … forest owners will need to manage forests to supply ecosystem services simultaneously with the production of revenue from wood products to help pay for that management'. They clearly distinguish wood harvest as a 'product' as opposed to an ecosystem service, with the clear implication that they believe only the 'products' can pay for the management of the forests. This approach downplays possible emerging market and financial instruments being considered for payment for ecosystem services (Kinzig et al. 2011).

This demand for more non-wood ecosystem services from natural forests is also an increasing challenge to the forest property rights of wood. The transaction costs[15] associated with this, whether conducted through an adversarial political environment or through ever more intensive and demanding negotiation processes, such as certification, will increase the costs of natural forest wood harvest (Gan 2005) At the same time if increasingly concentrated production from wood cultivation, with its higher yields and less contested range of ecosystem services, does not attract these same transaction costs this gives wood cultivation a distinct comparative advantage over more extensive and lower yielding natural forested lands. Zhang notes the difficulties in assigning property rights, which lead to free rider problems, for the many ecosystem services that forests provide. These are associated with much higher transaction

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15 *Transaction costs* are the costs of 'defining, protecting and enforcing the property rights of goods' and are contrasted with the *transformation costs* of turning materials into higher value goods (North 1990, p. 28).

costs. Critically this leads Zhang to the insight that '[t]he evolution of forest land tenure and persistency of public forestry, community forestry and household forestry can be well explained by the transaction costs' (Zhang 2001, p. 199).

As well as increased transaction costs for natural forest wood harvesting the demand for better non-wood values management also leads to natural forest being removed from production altogether. This has occurred through bans on logging including by changing land tenure to conservation reserves, or private land owners buying land for non-wood values and choosing not to realise the economic value of wood harvest. As this reduces supply of natural forest wood it can act to increase costs and so increase the competitive advantage of cultivated wood sources. Combined with increased use of reengineered wood products from chipped and pulped wood these cost pressures act to shift wood production to cultivated wood sources.

A significant claim made about wood in these discussions is its low embodied energy compared to other materials. Sutton (1999) highlights the irony in increasing environmental pressure to protect forests from wood harvest for non-wood values when there is a clear environmental advantage to wood products over materials that embody considerable fossil fuel energy in their production or are derived from non-sustainable mined sources. This is often deployed as a rationale for continuing to produce wood from extensive natural forests. However, the counter point could also be made that the demand for wood and its benefits could be met from other sources of wood production, specifically, cultivated wood sources. In these, the ability to produce large volumes of wood quickly can be land efficient and cost effective compared to harvesting wood from extensive forests with their relatively high costs of managing for conflicting non-wood values and higher haulage and management costs resulting from more dispersed wood sources. Reducing wood production from natural forests and valuing wood for its environmental qualities is not necessarily 'ironic', or contradictory, then. It is possible to derive the environmental benefit of wood using cultivated wood sources while also deriving the environmental benefits of protecting natural forests from wood harvest.

Using a dynamic model of ecological and economic change, Sohngen, Mendelsohn, and Sedjo (2001), predicted that climate change would increase global wood production, lower prices and increase welfare from these markets. They also found it would further the trend of wood production shifting from primary natural forests in high latitudes to plantations closer to the equator, as predicted by Sedjo and Lyon (1983). Cultivated trees are likely to offer greater flexibility for wood production in a world of fast changing climate and biosphere conditions. The short rotations and ability to shift production to more suitable climates and regions give significant advantages over natural forests, which are, relatively fixed to where they now exist. In addition, increased demands on natural forests to supply non-wood ecosystem services in response to climate change could further push extensive natural forest management for these values. Climate change responses are also likely to include pressure for an increased forest estate. Where this is met by the planting of new trees on previously cleared land it is likely that part of this will be through species and plantings that are suitable for wood production further increasing wood cultivation development.

As a number of authors have noted, there is a significant opportunity to address key global concerns for biodiversity and other ecosystem services from natural forests, and to mitigate the perceived conflict with wood supply, as the global plantation estate and ongoing wood saving technologies reduce pressure on natural forests.

3 The political economy of forest use and wood sourcing

> *From time to time there comes a tipping point when an occasion or set of circumstances clearly set the agenda for the future. Such a critical point may have been reached with the ascendancy of planted over natural forests for supplying many industrial commodities, some environmental services and even a few wildlife benefits* (Evans 2009, p. 1).

The use of natural forest as a wood source has started to diminish as wood cultivation grows in importance. An institutional and geographic separation is occurring between forest use and the cultivation of wood. Given this history, and observable evolutionary change in the use of wood and how forests are valued, this analysis will benefit from being framed in terms of social science theory that seeks to understand the nature of such change. For this the following chapter will look at a range of relevant theories.

Social, economic, technological and political contexts of wood production have undergone profound shifts. This is clear from the preceding environmental history. This change from gatherer-hunter to agriculturist in relation to wood production is well established, enmeshed in attendant social and environmental changes that are irreversible (Simmons 2008, p. 58). In this chapter we examine theories that seek to explain these forms of directional and evolutionary change in social and ecological systems.

Three broad areas of social science theory emerged in response to the initial literature reviews and exploration of this topic. These will provide useful understanding of the changes occurring in wood production and forest use systems. Each of these can be said to sit within a broadly defined political economy realm. The term *political economy* connotes analysis that is *economic* in the sense of pursuing questions of how people maximise their utility of limited resources, but *political* in that this economics is embedded in realms of politics and society.

The first of these three dimensions is the political economy of land and resource use. This includes basic theory of land rents and competition, problems of common pool resource use, theories of temporal and spatial patterns in land and resource use, debates about optimal strategies such as land sharing and land sparing and concerns about leakage and displacement. The second is the political economy of technology—the effects of changes in technologies. This includes consideration of the causative relationship of technology and other system changes. Its relevance is considered through the categorisation of path dependence, induced innovation and evolutionary economics. And thirdly, there are the roles of the social—the effects of the political, discursive and social on the process of change. This section of the thesis surveys theories of sustainability and globalisation that are vital to understanding the transition being studied. It looks at the role of politics, rent seeking and institutions[16] of forestry in particular in shaping processes of change. It considers the deep integration and complexity of socio-ecological systems as understood by actor-network theory and resilience thinking. Finally, it considers reflexive modernity—a description of contemporary modernity and its distinctive features that drive social change. The aim of this chapter is to use these themes and theories of crosscutting political economic processes to help understand the change described in the previous environmental history.

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[16] The term *institution* is used here in the sociological sense. A more detailed definition is provided in Section 3.3.2.

3.1 Land and resource use patterns: change at multi-scales

This first section will look at change in patterns of land use across the landscape of localities, nations and the globe. The transition of wood sourcing has had profound impacts on how landscapes and, particularly, forests are used. Several relevant bodies of theoretical thought have developed to explain changes in patterns of land and resource use. These include work that considers the role of land rents in shaping patterns of use, such as that of the Von Thunen hypothesis and related work in economic geography, forest transition theory, and temporal patterns such as the Kuznets curve.

3.1.1 Land rents and land competition

A useful starting place for the transition as expressed in land use patterns is central place theory—the Von Thunen model. The theory has been applied to an understanding of patterns of reforestation, wood production and deforestation (Ahrends et al. 2010; Horvath 1969; Hyde and Seve 1993) as well as being a basis for understanding forest transition (Angelsen 2007; Rudel 1998). Von Thunen, a German forester, created an 'Isolated State'. This was a geographically stylised and simplified 'state' and proposed a series of concentric circles of land use based on effects of land rents and distance from the market centre (Grotewold 1959). In this model he placed forests relatively close to this market centre. He argued this reflected a high demand for bulky wood fuel, in a time before fossil fuel took this role, the high cost of transporting these large volumes by ox cart, and the model's origins in a Germany in which there were no longer any forest frontiers, resulting in a reliance on reforestation (Horvath 1969). But, as Horvath notes, this is in contrast to the western model and consequent thinking of the economic geography of forests that are largely found at the periphery. He says: 'the forestry industry in the western world has for centuries simply been mining forests and has been able to substitute higher transport cost for decreased production costs' (Horvath 1969). This, then, explains the model more typical of contemporary forestry analysis in which a central market is located within a ring of agriculture, then a production forest area, and at the outer margin the forest frontier of unexploited forests (Angelsen 2007). Hyde's (2012) important treatise on forestry land economics exemplifies this thinking where he chose to 'focus on marginal shifts in land use' as a 'preferred choice' approach.

3.1.2 Forest transition

Forest transition theory discusses a given jurisdiction's shift from net forest loss to net forest gain—it is a 'historical generalization' of these observed changes (Rudel, Schneider, and Uriarte 2010, p. 95). Maher is often credited with formulating the basic theory (for example Barbier, Burgess, and Grainger 2010). It posits that the extent of a country's forested area goes through a period of decline during early stages of development, which then reverses in later stages. Meyfroidt and Lambin (2011) give an overview of national forest estates in transition around the world and define *transition* nations as those that have shifted from total forest loss to total forest gain. As a forest-focused subset of general land use transition theory it is of particular pertinence to the topic of this thesis. In particular, some parts of the literature look at the socio-economic forces that shift the focus to the establishment of planted forests for timber production which often forms part of the forest transition (Barbier, Burgess, and Grainger 2010). Barbier, Burgess, and Grainger (2010) note that the work done in this field has mostly analysed the reasons for the decline, but not the reasons for subsequent recovery. More detailed analysis of the reasons for the uptake of cultivated wood could reduce this gap in our knowledge.

3.1.3 Theories of temporal patterns in resource use

Kuznets' growth theory supposed that as economies industrialise, people move to the cities and become more educated, leading to social and cultural change. This explains how significant improvements are made to quality of life despite increasing population densities (Kishtainy and Abbot 2012). A key component of Kuznets' theoretical work (Kuznets 1955) was the *Kuznets curve*, which suggested that in its early phase industrialisation led to increasing inequality, but that this trend reversed as the industrialisation phase matured (Chowdhury and Moran 2012, pp. 3-4).

After the work of Grossman and Krueger (1991) this idea was assessed through an environmental lens. The basic idea of the *environmental Kuznets curve* is that environmental degradation will increase in the early stages of industrialisation as incomes increase to a certain point, but that environmental degradation will then level off and even decrease at higher income levels (Dinda 2004). It has been a commonly-used theoretical framework for exploring the intersection between economic growth and environmental degradation. There is a paradoxical nature to the process whereby income growth and environmental degradation growth are linked in the early stages of the process and then become decoupled at later stages. This mutation of apparent casual relations between income growth and environmental degradation is possibly reflected in the reported ambivalence of empirical data backing up the theory (Caviglia-Harris, Chambers, and Kahn 2009; Chowdhury and Moran 2012; Kijima, Nishide, and Ohyama 2010), The idea has some overlap with forest transition theory, with both postulating that environmental outcomes worsen during early industrialisation phases but subsequently improve.

Carson (2010) notes the contradiction of Kuznets curve with other earlier models which postulated that environmental impact was related to population, affluence and technology, so that increases in these led to increases in environmental impacts. These ideas were popular in environmental analyses such as those of the Club of Rome (Meadows et al. 1972) and the Ehrlichs (Ehrlich and Ehrlich 1972). The Kuznets curve, argues Carson, reflects measurable improvements in certain environmental criteria in rich countries, and therefore improves on this earlier work. Carson suggests a number of other possible causal factors are operating related to income increase, including increases in good governance, population density, technological change and shifting trade/consumption patterns. He laments the 'lost decade' when environmental economists were distracted by the pollution/income nexus whilst ignoring other driving forces (Carson 2010, p. 20).

3.1.4 The theory of sustainable yield

Achieving sustainable yield is a core goal in forestry. It is the logical response to the problem that drove the establishment of the institutions of forestry in the first place: how to manage forests so that wood supply is guaranteed in the long term. One of the most influential models for determining the optimal rotation (optimal pattern of logging trees from forests over time so that the capacity of the forest to supply wood is not diminished) is the model developed by the German forester Martin Faustmann (1849). It has been a source of contention within forest economics ever since. The Faustmann model determines the financially optimal rotation age by taking into account opportunity costs and discount rates (Brazee 2001). This method is likely to determine optimal rotation ages that are less than that which delivers the optimal biological yield (Raunikar and Buongiorno 2007). Nevertheless, Faustmann's ideas were endorsed by Samuelson (1976) who suggested that the key focus should not be on sustainability, 'but rather maximizing social welfare from the forest' (Newman and Wagner 2012, p. 217). This flexible approach to sustainability has some alignment with Solow's 'weak sustainability', which measures sustainability of total capital 'allowing substitutability between natural and man-made capital' (Gutés 1996, p. 147).

While these models of sustainability tend to treat wood as a renewable resource, wood has also been shown to act in ways that reflect a non-renewable resource [17]. For this, Hotelling's rule is applicable with its prediction of 'exponentially increasing prices' for non-renewable resources, which leads the market to determine an optimal rate of depletion (Gaitan, Tol, and Yetkiner 2006, p. 213). However, Hotelling's rule is known to be confounded by the empirical evidence which tends to show prices maintaining much greater stability than the rule would predict and even a tendency for prices to decline (Gaitan, Tol, and Yetkiner 2006). In the analysis by Gaudet (2007) he notes that modelling based on Hotelling's rule at its most simplest relies on assumptions of perfect certainty that are unlikely to occur in reality and act as a poor guide when trying to determine the actions of the market over the long term.

Newman and Wagner's work demonstrates that financial, or straight measures of wood generated, are not always effective measures of the goods that forests can contribute to welfare. It also acknowledges that sustainability might be impossible to know for forests, given ongoing changes in social values. It is further compounded by difficulties of assigning a monetary (or other unitary) value to many non-wood values or services. The changing valuations of non-timber goods have challenged the management of sustainable yield. Newman and Wagner (2012) note how in US public forests harvesting grew then crashed

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[17] See also section 5.4 for a discussion of this in relation to the Hubbert curve.

as changing values impacted on harvests through a range of non-market processes.

3.1.5 Land sparing and sharing

Also relevant is a body of literature pertaining to the ongoing debate about land sparing and land sharing (Fischer et al. 2011; Phalan et al. 2011). The transition described in this thesis has significant overlap with this body of work. Key debates within forest management discourse are centred on the potential for wood production intensification to allow greater conservation and other non-wood ecosystem service benefits from natural forests. This constitutes *land sparing,* where the natural ecosystem is spared the impact of an incompatible use by meeting the demand for that use from a smaller area of intensive production. The counter argument is that extensive management of natural ecosystems with multiple uses that include wood production provides a number of benefits (for example the idea that the ecological stability that complexity in natural forests provides is less likely to be found in intensive monocultural production systems). This would constitute *land sharing*—where various land uses are shared across a wider terrain. As well as being a normative discourse that seeks the best solution for land management, the issue of land sharing and sparing is also assessed from a positivist perspective. Here work such as that of Victor and Ausubel (2000) and Vincent and Binkley (1993) identify similar efficiency drivers in both agriculture and forestry that operate to shift production systems to intensification and, hence, a land sparing outcome.

The transition of wood production from natural forest extraction to wood cultivation can, at one level, be seen as land sparing. On the other hand, it also has expressions of land sharing. Not all wood cultivation occurs as industrial monoculture. There has been a significant increase in wood production from trees not from forests, in particular in the tropics and in response to demand for wood fuel. Here the trees are grown as part of agroforestry landscapes, as smallholder woodlots or as trees planted interstitially in existing landscapes. In addition, landscapes that see pasture replaced with plantation, even monocultures, can be managed in ways that lead to improved biodiversity outcomes (Brockerhoff et al. 2008).

The Borlaug hypothesis is a similar idea to land sparing. It proposes that intensification of agriculture can save forests by increasing agricultural production from the same, or an even smaller, area of land, thus negating the pressure to increase agricultural land at the expanse of forests (Angelsen and Kaimowitz 2001). This idea has been extended to forests and wood production, with intensive wood cultivation taking the place of agricultural intensification and the subsequent prevention of forest degradation through logging. In their paper, 'Using Forest Plantations to Spare Natural Forests', Sedjo and Botkin (1997) propose that the transition to plantations could be used to take pressure of natural forests, allowing other values to be furthered (see also, Ajani 2011b; Carle, Vuorinen, and Del Lungo 2002; FAO 2010a; Paquette and Messier 2009). This idea has been called the *plantation conservation benefit* (Pirard, Dal Secco, and Warman 2016). However, the Borlaug hypothesis is contested (Angelsen and Kaimowitz 2001), and the plantation conservation benefit has been found to be context dependent (Pirard, Dal Secco, and Warman 2016). In particular, these ideas suffer from the difficulty of translating a process that seems clear at a global level, but becomes less clear when observed at a national or regional level, where, for example, leakage effects can leave the potential benefits partially undone.

3.1.6 Leakage and the limits of knowledge[18]

Each of the above theories has been used to expound change in land use and natural resource use. But there are significant limits to the applicability of these in practice, in part because they are still developing and the systems involved are complex. Leakage research is an important analytical tool for understanding complex socio-ecological systems and working with the limits of that knowledge. Assessing leakage seeks to understand how systems might not deliver the results intended, particularly through unanticipated effects on interconnected systems.

Over the last fifteen years there has been considerable literature on leakage in relation to forest carbon stores, avoided deforestation and avoided log extraction impacts on greenhouse gas emissions (for example, see the literature reviews of Atmadja and Verchot 2012; Henders and Ostwald 2012). Concern over leakage and a need to measure greenhouse gas emission in ways that are consistent and efficient has led to the development of life cycle assessment, and related international standards (Guinée 2002). There is specific literature on protecting forests from wood extraction and subsequent leakage or displacement of log extraction effort to other forests (for example Chomitz et al. 2007; Gan and McCarl 2007; Meyfroidt and Lambin 2009). Measuring and incorporating leakage into forest conservation projects is a particularly challenging technical issue (Aukland, Costa, and Brown 2003; Rapidel, De Clerk, and Beer 2011) and ongoing research is required to improve understanding (Atmadja and Verchot 2012).

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[18] This section on leakage largely follows the text (and replicates Figures 5 & 6) from the published paper 'Forest conservation, wood production intensification and leakage; An Australian case', published in *Land Use Policy* (Warman and Nelson 2016). Copyright for this section rests with the publisher, Elsevier.

The process of quantifying leakage is an attempt to account for impacts that are unintended, and potentially external to the sphere of influence/concern of decision makers (Figure 5). The use of the term 'leakage' makes this accidental nature of the phenomenon clear. Leakage can occur as a consequence of bounded rationality (Simon 1972) or as a form of externality to the policy maker's jurisdiction or sphere of interest. Leakage assessment aims to quantify the impacts of an intervention beyond those explicitly understood and accounted for. It reflects recognition that the sphere of influence (or concern) for most policy interventions is a bounded or limited subset of the overall social and ecological systems involved (Wunder 2008). Limited knowledge of social and ecological systems or limited concern with externalities means that any planned intervention can result in positive or negative leakage—unintended effects that can either reinforce or negate intended outcomes. Because of this, assessments of leakage provide essential feedback for monitoring and reviewing policy design.

Leakage assessment involves comparing the net outcomes following an intervention, with a scenario in which there is no intervention—the counterfactual. Assessments can be conducted *ex ante* to predict leakage, or *ex post* to review leakage following a policy intervention. The former approach requires modelling of both the counterfactual and intervention scenarios, while *ex post* assessment can use data from the intervention scenario and compare this to a counterfactual.

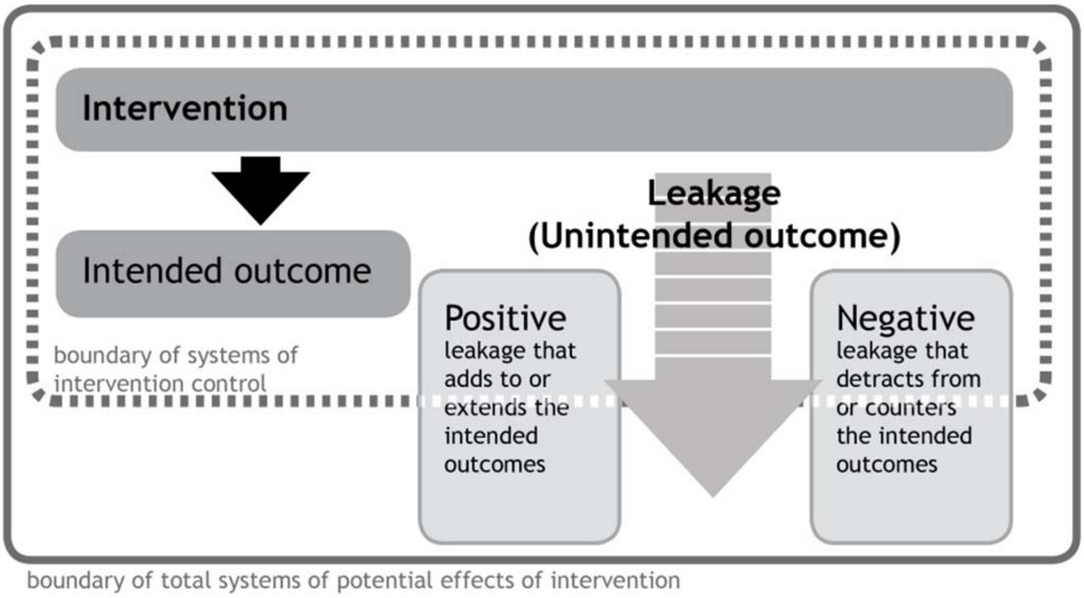

Figure 5. Basic model of leakage and its relationship to intended outcomes.

A proliferation of terminologies and typologies accompany the growing field of leakage assessment, with potential for confusion (Aukland, Costa, and Brown 2003). A distinction has been made between weak leakage—general displacement of demand—and strong leakage—the direct unintended consequences of a policy intervention (Henders and Ostwald 2014). The former tends to focus on shifts in demand without attributing causality to specific drivers. Weak leakage can be a useful concept in some cases such as monitoring the net outcomes of atmospheric CO_2 balance. Strong leakage, can be useful in seeking to understand the effects of a specific change in policy.

A commonly used distinction for different types of leakage is *direct* and *indirect*. Direct leakage is said to occur when the targeted activity (for example, wood production) is shifted elsewhere. Indirect leakage occurs when the intervention causes other types of activity to occur that have impacts on intended outcomes. Leakage that occurs within the sphere of influence of an agent is often referred to as local leakage. Leakage outside the same sphere is referred to as distant leakage—often at risk of being discounted by local agents. Other typologies reflect the alternative means of triggering changes in agent behaviour. Changes triggered directly by an intervention are referred to as primary leakage, while those triggered indirectly by market signals are referred to as secondary leakage. Figure 6 summarises a typology drawing on recent reviews of leakage as a concept (Atmadja and Verchot 2012; Aukland, Costa, and Brown 2003; Henders and Ostwald 2012).

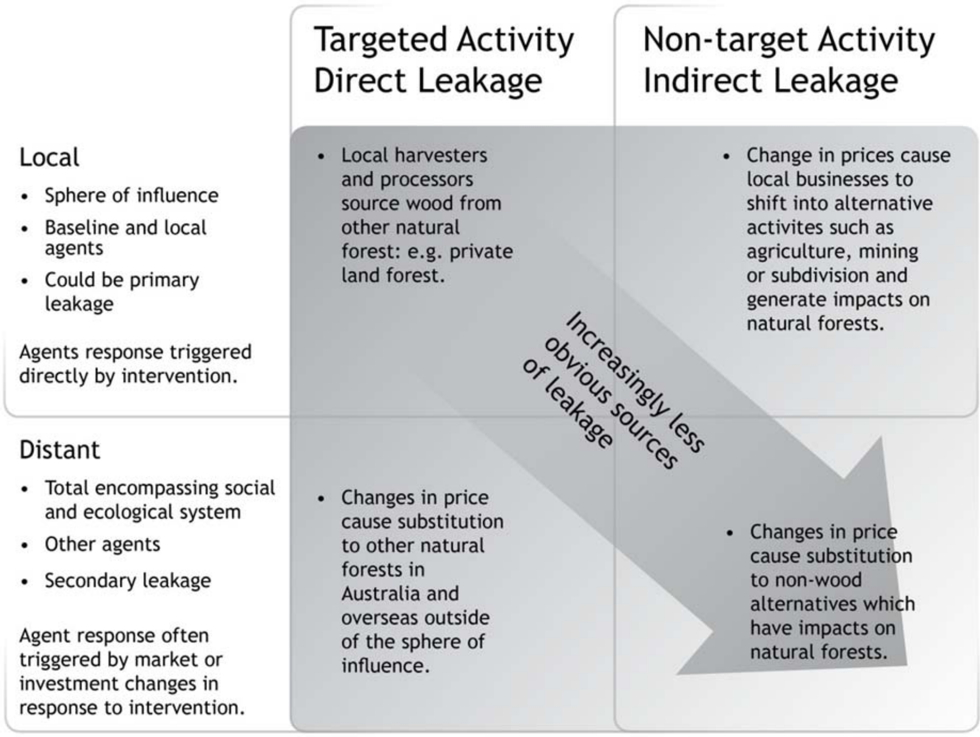

Figure 6. Matrix of main distinctions of leakage sources and types

3.2 Technology: path dependence, innovation and evolution

> *Even though evolutionary economics have been gaining importance in the last decade, the evolutionary nature of resource, forest, regimes has been unable to attract the attention of either economists or forest managers* (Kant 2000, p. 290).

As a fundamental factor in social and economic systems, technological change has the effect of constantly changing system dynamics. In many ways this is significantly at odds with the experience of those involved in the field of forestry, where there is a strong emphasis on equilibrium, and change itself is likely to be approached as cyclical. This is consistent with neoclassical economic thinking, whereby technological change and its trajectory are treated as exogenous so that the system studied can be balanced in equilibrium. However, evolutionary approaches to economics and economic geography differ from neoclassical and institutional thinking, in part by dint of their emphasis on dynamic system characteristics (Boschma and Frenken 2006). The preceding environmental history section highlighted how the socio-economic nature of wood production is also driven by forces that are rapidly evolving. Changes are occurring that are irreversible (or very robust at least) and directional rather than static or cyclic. Technology theory is important for its insights into system change, system lock-in or path dependency and for understanding the role of innovation.

Ruttan (1997) looks at three bodies of economic theory that describe technical change; path dependence, induced innovation and evolutionary economics. Each of these is covered here. He also cautions that each has provided valuable insights but has reached its 'dead end'. He proposes that work needs to progress on a 'general theory' of technical change and its role in growth, pointing to various options for integration of these approaches.

3.2.1 Path dependence and lock-in

While equilibrium is central to mainstream economic theory, in particular microeconomics, many economists have sought to reach beyond this to understand the obvious change dimension of technology (for example, Boulding 1981; Nelson and Winter 1982). Path dependence theory suggests that the evolution of economic systems does not gravitate to a single optimal equilibrium but that 'accidents of history' along the way can influence outcomes. These accidents might not always be accidents in the sense of being unintended but could be, for example, the unintended development of a particular technology, or the unintended consequences of a new technology. For example, technological innovation might be induced by a particular set of unique circumstances in a separate system. Such technologies can also be transferred to other places, influencing other systems in new and unplanned ways—hence 'accident'—even though those other systems do not have the conditions necessary to induce that particular technological innovation in the first place. In addition, these are unlikely to easily change back to the previous state. As well as being an agent for change in economic systems, new technologies can involve the establishment of considerable physical, institutional and financial infrastructure to support and utilise the technologies. With these investments significant system inertia or 'lock-in' for the new conditions comes into being. The QWERTY keyboard is an oft quoted example of a technology producing economic system path dependence or lock-in (David 1985). In the case of wood/forest socio-ecological systems, an example might be the development of intensive tree cultivation technologies in response to the compete exhaustion of forests in central Europe. These were then exported to other places suffering the same problem, or applied in quite different circumstances; for example, where there are extant natural forests still in place, such as in European colonies. This is having major impacts on how wood/forest socio-ecological systems changed and became established, and subsequently resisted change to alternative forms.

In addition to the influence of technological 'accidents of history' there are 'accidents' of choice of policy that will affect the adoption and pursuit of innovation (or not). Diamond (1997) points to the profound impact that the political institutions of China and Europe in the middle of the last millennium had on the deployment of new technologies in navigation: new technologies that dramatically affected the development of the world system in the second half of the millennium.

Path dependence or 'lock in' can come about through numerous mechanisms. For example, switching barriers (institutional and financial costs associated with changing supplies that inhibit change) could mean that changes in wood supply from varied natural forest logs to consistently sized plantation logs might make changes back to natural forest logs unlikely following investment in new machinery. This, then, becomes a type of 'lock in' that reinforces the trends and trajectories of change in a unidirectional way without allowing return to earlier conditions. Another form of 'lock in' is the role of increasing capital costs in internationally competitive wood product manufacturing plant (Hyde 2012). Supplying streams of consistent quality wood is likely to provide a comparative advantage to industrial plantations over natural forests. This in turn 'locks in' a mutually supportive pattern of colocation of processing and wood cultivation investments.

3.2.2 Induced innovation

Raw wood is a basic input to wood product manufacture, and there are strong economic incentives to reduce the costs involved in raw wood supply—this induces innovation. Ajani (2011b, p. 53) refers to the 'uncoupling of wood from finished wood products through wood saving,' in her review of the divergence of relatively stagnant world log production versus growing consumption of wood products. Innovation in industry is focused on saving on the limiting factors in production (especially those with highest costs) which includes the raw logs and labour (Ajani 2011b, p. 53). The use of wood for paper has undergone similar innovation. For the period 1980 to 2007 global paper consumption grew by 3.2 per cent per annum while the use of wood pulp to meet this demand only grew by 1.4 per cent a year. The shortfall was made up by a 5.2 per cent per annum growth in recycled paper and a 3.0 per cent per annum growth in non-wood pulp sources (Ajani 2011b, p. 56). Hyde (2012) notes global demand for pulp logs growing by just 10 per cent from 1980 to 2000 while paper and paperboard production grew by 90 per cent in the same time period. The volume of logs harvested has not needed to keep pace with increases in the consumption of wood products. This is born out in international data showing per capita wood consumption declining consistently over previous decades despite increases in per capita economic growth and consumption (Sewall 2003).

Changes in the technology of wood processing have had a number of effects on wood production. Technology has made tree harvest easier, with chainsaws and heavy machinery being obvious examples. But, equally, in the area of wood processing there has been ongoing improvement. In the latter half of the twentieth century commercial wood processing operations became more integrated. Parts of logs that were once wasted are now used in secondary products such as pulp, energy, and reconstituted wood products. The Vice President of Weyerhaeuser, speaking to the Forest Products Society in 1975, observed that in 1948 only 20 per cent of their logs in Western Oregon were turned into usable product. By 1963 this was 61 per cent and by 1973 it was 79 per cent (Meil et al. 2007, p. 84). In the thirty years from 1975 to 2005 significant efficiencies continued to be made in the North American wood products industry. Meil et al. (2007) calculated that 15,000 hectares of annual forest harvest were avoided as a result of these efficiencies. And it was not just better log utilisation—an ability to utilise smaller and poorer quality logs so that harvest activity can be more contained with lower harvesting costs also occurred. Ongoing improvements in logging efficiency also support the shift of wood production to intensive wood cultivation through the draw of efficient mechanised harvest of uniform stands of trees in wood plantations (Lucier, Hinchee, and McCullough 2001).

Changing technologies (along with growing populations) are likely to have contributed to the speeding up of the process of forest exploitation in tropical countries in the later part of the twentieth century (Shearman, Bryan, and Laurance 2012), compared to the longer pattern of exploitation in places such as Europe, and North America when there was not the advantages of chainsaws and motorised transport.

A commonly cited source of future industry growth is the predicted ongoing growth in China's economy. On the other hand, Ajani (2011b) argues that China has been highly successful at adopting wood saving strategies that have avoided triggering the much-publicised wood shortage of earlier decades. China also leads the world in terms of recycled content in its paper production. Indeed, this could even be seen as a deliberate strategy—by not forcing up global demand China has helped maintain the low international wood pulp prices that work in its favour. Prices for China's wood imports declined by 3.7 per cent per annum, despite a fourfold (423 per cent) increase in volume, over the decade commencing 1997 (Ajani 2011b, p. 59). These figures also suggest that the rest of the world has had no shortage in supply of wood, given that the increased demand from China has failed to evoke any sort of price rise. In addition, China has embarked on an ambitious project of plantation establishment, which is aimed to reduce import dependence. Ajani (2011b) also observes that if the world as a whole copied China's paper efficiency global wood consumption could be shrunk in the order of 11 to 21 per cent. She adds the qualification that there would be problems in achieving this, such as limits to total world volumes of recycled paper and the half-life of fibres. Nevertheless, it is a classic case of resource scarcity inducing innovation.

Another significant factor in reducing costs is labour. Like most manufacturing industries ongoing technological change is reducing the number of people involved in processing wood. Aside from driving a globalised demand for wood and agricultural land, industrialisation also developed the mechanisation that dramatically altered rates of processing timber. A hand powered pit-saw sawmill of the Middle Ages could output 100-200 board feet[19] a day, water powered sawmills of the seventeenth century increased this to 500-3000 board feet a day, before the steam powered sawmills of the nineteenth century boosted output by another order of magnitude to 20,000-40,000 board feet a day (Williams 2002).

Hyde (2012) makes the observation that as wood product manufacturing has become much more capital intensive the incentive for those capital owners to have uninterrupted wood supplies has increased. One of the significant advantages that plantations offer over natural forests is their ability to grow relatively large volumes of logs with a consistent size, thereby allowing for more efficient processing (reducing both wood costs and labour costs).

These processes of induced innovation are consistent with expectations of the Boserup theory. The theory espoused by Danish economist, Ester Boserup, was that technological innovation comes about in response to increased demand resulting from population growth. This was proposed in opposition to a Malthusian perspective that population growth is limited by available food production (Boserup 1965). Applied to wood production, this theory would support the idea noted here that technological change in wood production is caused by increased demand or restricted supplies. Changes in demand for non-wood services and values from natural forests and forests more generally are also creating pressure on wood supply, either through regulatory restrictions on

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19 A board foot is a volume of wood of 144 inches cubed (usually described as a volume 12 inches by 12 inches by one inch—one inch is 2.54 centimetres). It is commonly used in the US and Canada to measure wood volumes (Oester and Bowers 2009).

harvest or increased protection of forests. In the same way that population increase or growing wealth increases demand, these restrictions on supply can act to induce innovation in wood cultivation and wood product development. Ecosystem services are both non-excludable and non-rivalrous, or public goods, mostly without any established pricing signal mechanisms. Therefore, it is often left to governments to determine their allocation, which entails regulatory restrictions on harvest in natural forests. These can also occur in relation to tree cultivation but they are less likely to impact on wood productivity, as it is accepted that the land has been allocated primarily for that purpose.

The above is also consistent with the Porter hypothesis, that environmental regulation can induce innovation and thus have a positive effect on economic competitiveness (Howarth 2012). Restrictions on forest harvest arising from environmental regulation (through harvest restrictions and regulation) will generally contribute to a reduced harvest. It is possible that environmental regulatory restrictions on harvest combine with increasing marginal harvest costs as a double act to raise the costs of natural forest wood production. It seems the experience of wood production from natural forests would contradict the Porter hypothesis in relation to wood productivity in natural forests. However, as noted above, it is probably the case that innovation is finding expression in the development of intensive wood cultivation and wood saving technologies. In this sense then, the effect of increasing environmental regulation can be seen to have an additional positive impact on natural forests by furthering the wood sourcing transition, and thereby supporting the Porter hypothesis.

3.2.3 Evolutionary economics

Boschma and Martin (2010) say theories on evolutionary economics must meet three conditions if they are to qualify as such. Firstly, they need to be 'dynamical', that is describe a process of change; second, the change will be ‘irreversible’ (not cyclical nor returning to past states); and third there must be explanation of the ‘generation and impact of *novelty* as the ultimate source of self-transformation’ (Boschma and Martin 2010, p. 5). The above body of theory meets these criteria well. It focuses on processes of change and in particular a dynamism that goes beyond cyclical change—that is, it is unlikely to be reversible. New wood sourcing from cultivated wood is the result of responses to conditions that are novel in numerous ways. This is where technological path dependence can be seen to mesh with the idea of creative destruction seen in a dynamic economy with newly emergent technologies. Creative destruction, an idea first proposed by Joseph Schumpeter in 1931, has been a strong counter-current to the mainstream of economic thinking that is ‘focused on competition under static equilibrium’ (Hart and Milstein 1999, p. 23). The role of creative destruction goes beyond just changing economic systems when ‘[n]ew sectors attract resources away from old ones,’ but leads to conflict in political and economic arenas (Acemoglu and Robinson 2012, p. 84).

There are useful pointers in this body of theory that help to explain the emergence of wood cultivation as an alternative to natural forest extraction. Evolutionary economics suggest that new methods of production and marketing and new institutional arrangements can arise that have more resilience or capacity than old methods. These new methods then become dominant, fundamentally altering the systems in the process.

3.3 Social dimensions: sustainability, institutions, networks and resilience

3.3.1 Sustainability

The quest for sustainability is at the heart of the mission of stewardship forestry. Yet the notion of sustainability is fraught (Basiago 1995; Davison 2008; Vos 2007).

Vogt et al. (2007) speculate that large and complex societies have a momentum that makes change hard and forces them into unsustainable rates of exploitation. In particular, sub-groups that are mostly dependent on the resource are likely to be unaware of emerging limitations. They will continue to act on the belief there are no constraints upon their way of life: 'This widely held view encourages the exploitation of forests and is a view that resurfaces throughout the history of global societies and forests'. Vogt et al. (2007, p. 6) go on to observe that in the twentieth century there has been a growing awareness of the finiteness of the forest resource and a need to address exploitation before it arrives at its logical conclusion of complete exhaustion. In previous times, societies that had exhausted their forest resources either collapsed, expanded to find more, or went through a period of both. Examples given include, Sumer, Ancient Greece, Easter Island, the Maya and the Muslim Mediterranean (Vogt et al. 2007, p. 6). As another example, Simmons (2008, p. 74) points to the progressive shift in sugar production across the Atlantic from Madeira to Gran Canaria to Barbados. Each time the soils for cane growth and the forests for fuel to boil the cane juice were quickly and unsustainably exploited.

Colander (2005) notes the obvious tensions in the use of the term 'sustainability', drawing the reader to ask: sustainability of what? For whom? In the case of stewardship forestry, institutions have been built on the logic of sustainability of wood supply and the maintenance of forest cover. Nevertheless, Simmons, noting the ongoing flux of climate over the period of human evolution, even in the relatively stable post glacial period of the last 11,500 years, observes that, '[n]one of the scientific investigations into the last 10,000 years has indicated a stable state of nature' (Simmons 2008, p. xiv). There has been widespread human interaction with, and alteration of, the terrestrial and atmospheric natural systems of the earth. In this context, Simmons says any discussion about ‘sustainable’ becomes problematic simply due to the lack of an obvious stable reference point against which ‘sustainable’ can be measured. This is also true for the term ‘natural’ when it is used to indicate some sort of baseline.

From the perspective of the forest stewardship advocates who came to prominence in the nineteenth century, sustainability in relation to forests was defined in terms of supply for wood. This has changed over time as non-wood qualities of forests have become increasingly valued. This means that sustainability, as the capacity of a system to provide certain goods/services/values over a long period of time (or indefinitely), is itself subject to the changing values defining sustainability (Colander’s ‘what?’). In addition to this, the applicability of the definition will vary widely depending on scale. For example, at a local level the clearfell logging of an old growth forest may, from the perspective of a current generation, be deemed unsustainable. Old growth values held in esteem will cease to exist in that location. But, if the regional forest area as a whole is logged on, say, a three hundred year rotation, along with a comparable controlled reduction in loss to wildfire impacts, than it could be argued to be sustainable from the viewpoint of maintenance of old growth values at the landscape level. In other words, seen at one scale an activity might not be considered sustainable, but at another the same activity can be part of a usage pattern that is sustainable.

This line of thought can also make sense of temporal variables as well as spatial. The logging of a patch of old growth forest now will have complex implications for future generations that further complicate the sustainability reckoning. Of course, as well as these problems of defining the scale and temporal dimension of what is sustainable, values themselves are changing. The act of setting aside public forest lands in the early twentieth century for wood production was intended to achieve sustainability. But towards the end of the century and into the twenty-first it was increasingly seen as unsustainable.

Questions of sustainability of natural resources (including forests and wood growth) also lend themselves to a consideration of intergenerational economics (Sandler 2001). The benefits of public goods such as new knowledge, biodiversity and biosphere health can benefit multiple generations, but this does not always get factored into current cost benefit analysis. It is an area of inquiry and academic endeavour particularly pertinent to the economics of forests and wood, given the long-time cycles involved.

3.3.2 Institutions

Institution is a key concept in understanding social and economic systems and its definition can be broad and contested (Nabli and Nugent 1989). North (1995, p. 3) defines *institutions* as being broadly about the 'rules of the game of a society or more formally … the humanly devised constraints that structure human interaction' (and, thus, different to organisations), 'the players', or groups working to some common purpose, and guided by the institutions of their 'game'. Nabli and Nugent (1989, p. 1335) expand on this, positing three basic characteristics common to *institutions*, the first of which is 'rules and constraints' as per North's definition. To this they add a second characteristic, 'their ability to govern relations among individuals and groups', and a third—*institutions* having predictability. They proceed to recognise that *institutions* can include the full suite of rules and constraints that 'governs the behavioural relations among individuals and groups' (Nabli and Nugent 1989, p. 1335), whilst including formal organisations, as well as rules, contracts and constrains, both informal and formal, voluntary and enforced. It is within this broad encompassing definition that this thesis will discuss *institutions*.

Institutions are a central feature of social and economic systems (including those involving wood and forests). The study of collective action, the expression of institutions through organised behaviour, is important to understanding these systems. Collective action can occur in a number of forms. In the form of behaviour by special interest groups such action can be deleterious to optimal efficiency for the economy or broader society (Olson 1965, 1982; Stigler 1971). Such behaviour has been documented in relation to forestry (Kishor and Damania 2007; MacIntyre 2000).

'Cultural freeze' is a concept related to migrant communities that become 'frozen' in the beliefs and values carried with them from the past, usually connected to their homeland (on this see McCartney and Gill 2007). This concept has some potential to be applied to understanding communities involved in a particular mode of using forests and how they deal with change. Simmons (2008), talks about the romantic appeal of the 'old ways'. He discusses the shift from traditional agricultural landscapes and societies to modern ones in which fossil fuels and associated technologies have dramatically altered social mores. He notes the appeal of rural landscapes and lifestyles in tourism and the lingering interactions of preindustrial agrarian society with the globalised modern world through the Disneyfication of these landscapes. This occurs via tourism, subsidies to farmers to maintain loved practices, and the small pockets of self-sufficient communes founded on religious and/or alternative principals. These are variations on frozen cultural attachments.

Cultural freeze may have contributed to the resistance to transitions to plantation wood in Australia. A strong identity with the rural lifestyle and its social cohesion that logging from natural forests has created builds a resilience and resistance to the external forces of change. In the Australian context this resistance has come up against the counter push from parts of the community wanting natural forests protected from logging, also, as we will see, ironically driven in part by resistance to perceived changes the 'old ways'. With politically active change agents seeking to end old forest practices, local forestry communities have become the focus of much frustration at the changes being forced on natural forest logging. The not insignificant economic and technological forces also pushing the change are by comparison impersonal and faceless. It is possible that they are often not to subject to the same personalised anger and public attack, despite potentially being the more influential force for change, because of this impersonal quality.

Many forests are or have been common-pool resources, with a number of influential models explaining the problems they suffer when exploited as such.[20] Elinor Ostrom (1990, pp. 2-7) notes three models that describe core problems with common-pool resources. There is the 'tragedy of the commons' (Hardin 1968), in which lack of ownership leads rational players to maximise their use of the resource, leading to overexploitation. The decision-making of actors in this tragedy is clearly evinced in the second model; the prisoner's dilemma. In this model each agent acts rationally to best their own outcomes but will contribute to an overall worse outcome for everyone. Finally, Ostrom refers to the work of Olson (1965), in which Olson finds that actors will shirk their fair contribution to a collective action if they will benefit anyway—free riding—such that if all, or many actors, choose this option, the collective action fails, again leaving everyone worse off. However, Ostrom finds that these models have limitations, especially in how they come to be applied to policy solutions. She notes the

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[20] The following paragraph closely follows the text that appears on pages 26-27 of the paper, 'Decentralisation and forestry in the Indonesian Archipelago: beyond the *big bang*', published in South East Asia Research (Warman 2016). Copyright for this paragraph rests with the publisher, Sage.

existence of a body of work pointing to only two outcomes. One, the 'leviathan' position, takes the view that an overarching central government can see the problem from above the self-interest of individuals. Such a government will use rational decision making with all available information to assert an optimal outcome. The second position advocates privatisation. Here clear private ownership removes the problems of the common-pool resource. This leads to optimal efficiency of resource use through the discipline of the market[21]. Though often framed as opposite approaches, both positions require an external agent of control (Ostrom 1990), typically a central government. Despite this, there is evidence that self-organised community governance is an effective mode of common-pool resource management (Agrawal 2003; Ostrom 1990; Wunsch 2013). Given that such self-governing systems are possible, then, this becomes a potential third way—one where the actions of the external central agent can support the conditions necessary for the development of decentralised governance. This would include giving jurisdictional rights to a local or decentralised level of governance, but could well require other actions such as building the necessary supportive culture, both at central and local levels.

3.3.3 Actor-network theory

In teasing out a clear distinction between nature and culture, it is easy to get stuck in the debate between a constructivist insistence that the terms are just social concepts that exist in language, and a realist view that there is a material difference in things themselves which have causative functions in the world (Kortelainen 1999). An approach that some social researchers use to tackle this problem is that of actor-network theory (Law 1992). This theory finds that things

[21] See (Berck 1979) for an early discussion of the differences in approaches to optimal forest timber harvest regimes between private and public land management in the US.

(and their essential material nature) and humans (and their social and discursive characteristics) influence and shape one another and that this is fruitfully understood and critiqued from a perspective that encompasses both qualities. It argues that there are plausible networks of influence in both directions and therefore one can assign some sense of agency to both things and subjects. Thus '[n]ature is at the same time real, social and imagined' (Kortelainen 1999, p. 236).

For the study of wood production and forests in this thesis, this approach provides a useful conceptual basis for the adisciplinary and grounded approach that is taken. It recognises the multifaceted nature of the problem and the phenomenon. In relation to forestry, to paraphrase Bruno Latour:

> *[Forestry is] too social and too narrated to be truly natural; the strategy of [foresters, timber companies and forestry bureaucracies] too full of [yield analyses and forest mensuration] to be reduced to power and interest; the discourse of [forests and wood] is too real and too social to boil down to meaning effects* (Latour 1993, p. 6)[22].

Thus, the topic of study is approached from multiple directions. None alone reveals an understanding sufficiently removed from the subject, but, taken together, there is the potential for a deep analytical penetration. In this way the thinking of actor-network theory provides a rich way of being able to fully consider the '*patterned networks of heterogeneous materials*' that make up the network of elements that form the 'social' (Law 1992, [author's italics]). Given the theory's origins in social science this might also give a different insight into the dynamic feedback characteristic of subjects in a networked social system from resilience thinking with its natural science origins. So, for example, actor-

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22 Latour's actual words (in translation at least) were: 'The ozone hole is too social and too narrated to be truly natural; the strategy of industrial firms and heads of state is too full of chemical reactions to be reduced to power and interest; the discourse of ecosphere is too real and too social to boil down to meaning effects'.

network theory offers a 'more encompassing concept of agency that extends beyond human intentionality' (Dwiartama and Rosin 2014, p. 1). It extends agency to the nonhuman by considering its effects on the human and other nonhuman 'actants', specifically by focusing on the relationships between these networked elements (Dwiartama and Rosin 2014). Importantly, it also embraces the discursive within its sphere of consideration. When the *social* within the socio-ecological system is observed, then phenomena are found that 'are not only cross-scale in nature, but cross-dimensional (or in other words, cross-ontological)' (Stokols, Lejano, and Hipp 2013).

3.3.4 Resilience thinking—resilience, adaptability and transformability

Holling's (1973) seminal application of the idea of resilience to ecological and environmental discourse was a challenge to the predominance of equilibrium concepts in ecological thinking (Folke et al. 2002; Walker and Cooper 2011). The concept of resilience is applied to a wide range of 'interdisciplinary work concerned with the interactions between people and nature' (Carpenter et al. 2001, p. 765). In relation to this investigation, a key question is: to what extent can the transitions around wood extraction to date be undone, or, asked another way, do they themselves constitute new states, or are they part of new states of larger systems (industrial modern society for example) that lend changes backwards little chance? Carpenter et al. (2001), in their paper titled 'Resilience of what to what?', point to the specific questions needing to be asked in order to take resilience theory beyond a metaphorical instrument to one that allows measurable insight. Their examples are focused on ecological systems, with examples of 'resilience of' being clear water states in lakes or grass-shrub ratios in rangelands, and 'resilience to' being short term changes in phosphorous inputs or changes in herbivore and fire regimes. Nonetheless, the framework for moving beyond metaphor to the specific and even empirical could fruitfully be applied to changes in the socio-economics of wood production and forest management.

A resilient state is a system condition robust to a certain level or type of fluctuation in state variables (factors or features that define the state). A particular resilient state can be known as a *basin of attraction* or simply *basin.* When a system is subject to change that is beyond the capacity of the system to maintain itself it will change into a new basin (a change sometimes referred to as *transformation*).

There are three attributes of socio-ecological systems that determine their future trajectories: resilience, adaptability, and transformability (Walker et al. 2004). The first attribute is *resilience* and its four components of latitude (the elasticity, or extent to which a system can be altered but still recover to maintain its function), resistance (the ability of the system to withstand change), precariousness (how close the system is to its limits—loss of function) and 'panarchy' (the influence on the system of other systems nested within, containing or influencing the system). The second attribute is *adaptability,* referring to the capacity of actors in the system to perpetuate its resilience through maintenance of its key features despite change in socio-ecological system conditions. The third is *transformability*; the capacity to create a new state when the functioning of the current state becomes 'untenable.' Qualities that contribute to the resilience and transformability of socio-ecological systems can be characterised as *attractors*—factors that act to stabilise or hold a system in place and act as positive feedback—and *stressors*—factors that act to destabilise a system, and potentially shift the system out of its basin of attraction and into a new state (Young 2010).

Actors are important parts of systems. Their dynamism can influence the resilience, adaptability and transformability of basins. They are important feedback mechanisms in the socio-ecological systems. They will invest in maintaining existing structures and functions that can contribute to socio-ecological system resilience (or resistance to transformation) through a cycle of positive (or negative) feedback (Pierson 2000b). Conversely, this can work to miss transformation opportunities during crises because of inbuilt institutional tendencies to repair as fast as possible to a pre-crisis state (Herrfahrdt-Pähle and Pahl-Wostl 2012). Other institutional attractors can include sunk costs in infrastructure, plant, land, and technologies (David 1985); political and governance structures such as legislation, regulation, and administrative arrangements, or political capital (Pierson 2000a); distributional coalitions, especially those that coalesce into forms that inhibit an optimal transition in line with new available technologies (Olson 1982); and investment of identity in social and cultural norms forged within the system. These institutions can create a degree of resilience despite the fact that changes in the state variables (for example, population, wood product demand, technological change and long term economic growth) of these socio-ecological systems might otherwise create a system of ongoing change. In effect, actors and institutions can play an important part in giving the socio-ecological system a form of 'lumpy' change such as that described by the term 'basins' in resilience thinking.

Another change-affecting factor is parts of the global socio-ecological system in different basins impacting upon the interconnected socio-ecological system—panarchy effects. For example, changes in wood production, consumption, or forest use in one polity (say, increasing plantation wood production) can change the socio-ecological system in other polities (by, say, decreasing natural forest wood demand). The location of these socio-ecological systems within different basins at national or subnational levels within the world system can also expose systems to the learnings of polities that have already faced similar challenges and undergone similar changes, thus altering systems simply by an infusion of new knowledge.

Resilience concepts provide a useful framework for describing complex sets of interacting phenomena as whole systems, in a way that analysis through the silos of traditional disciplines or bounded foci on selected aspects of the larger phenomenon cannot. Understanding the crossover between natural and social systems is critical to addressing real societal problems (Macilwain 2014). Further, interconnected biological and social systems in forest and wood production are obvious areas for the application of ecological theory to social and economic systems—both as metaphor and analogy (for example, Hodgson 1993; Kant et al. 2013). Application of biological metaphors in social science has a plausible basis, given the presence of shared system characteristics. In particular, the larger systems in question have complex adaptive parts that are affected by the total system. This is fundamentally different to mechanistic systems in which the parts are unaffected by the actions or processes of the system as a whole. While the application of metaphor in scientific endeavour is open to challenge as a 'superfluous distraction in intellectual endeavour', its application can challenge 'beliefs about reality' and be a 'source of creativity' (Hodgson 1993, pp. 18-21).

3.3.5 Risk society and reflective modernisation

> *Politicians claim not to be in charge, since the best they can do is to set the regulatory framework for the market. Scientific experts say they merely create technological opportunities but that they do not decide whether and how these are implemented. Businesses say they are simply responding to consumer demand. Society has become a laboratory with nobody responsible for the outcome of the experiment* (Beck and Kropp 2007, p. 609).

Beck, Giddens, and Lash (1994) argue that the current preoccupation with environmental risk is a consequence of modern efforts to conquer nature and overcome natural hazards. The success of this modern project and the resulting dominance over nature has, however, led to the replacement of natural hazards by risks—'manufactured uncertainties'—artefacts which are internal to society rather than external (Beck 1992; Giddens 1994).

This creates a fundamentally different proposition for how these risks are addressed. The exploitation of natural resources becomes inherently tied to the social production of risk. 'These risks can no longer be scientifically measured or rationally calculated because risk is not an objective reality', sited outside society, 'but a socially constructed response to complex and unknowable possibilities' (Lucas and Warman submitted). Beck labels debates over how to respond to tensions in resource use within the socio-ecological system as 'risk conflicts', in which the debates are about different definitions of the risk (Beck 1992).

Anthony Giddens describes a critical difference between modernity and pre-industrial society as being the extent to which power and authority now rest in social negotiation , trust and rationality. This is in juxtaposition to the previous reliance on external authorities such as gods, divinely appointed rulers and nature (Giddens 1990). As a result, in the risk society, there is no longer any higher or independent authority that can be appealed to in determining the outcome of a conflict. The multiple actors and various discourse coalitions in the wood/forest socio-ecological system all have their claims to legitimacy and knowledge, meaning the 'expert' no longer has the power to end the dispute (Beck, Bonss, and Lau 2003) and risk conflicts occur within a network of interconnected individual and systemic interpretations of risk (Beck 1992).

This process of negotiating risk within society is described by both Beck and Giddens as 'reflexive modernisation' (Beck 1992; Beck, Giddens, and Lash 1994; Giddens 1990). Belonging to particular groups (nation, profession, class) is no longer pregiven. These become understood as socially constructed and thus subject to choice. Here, then, as the boundaries of *in* and *out* become porous, traditional authorities and arbiters of conflict become substituted with 'cooperative decision making through ad hoc, sub-political negotiations' (Beck, Bonss, and Lau 2003, p. 28).

Another aspect of reflexive modernity that is relevant to this thesis is the re-envisioning of society's relationship to nature. As Lucas and Warman (submitted) note, '[i]n reflexive modernisation nature is no longer seen as an unlimited resource external to society'. In realising this, the fallacy that science is an instrument of social progress that will demystify and then allow control of nature becomes apparent (Beck, Bonss, and Lau 2003). Indeed, scientific arguments and 'facts' might be invoked to justify quite divergent positions on the future of wood/forest socio-ecological systems. These 'facts' can then masquerade as 'objective' arguments that serve only to mask the political, social and ideological motivations of those making the arguments (Corner 2012; Kahan, Jenkins-Smith, and Braman 2011). This, then, is an important conceptual frame through which to view the debates that are covered in this thesis. Debates over use of forests, wood production, the possibility of sustainable forest management, or the merits of land sharing versus land sparing approaches, all occur within this space of reflexive modernity.

3.4 Summary

Understanding the transition as it is reflected in spatial patterns (where activities do and do not occur) can lead to identification of patterns in land use such as those discussed in Von Thunen's model and forest transition theory. Temporal dimensions can be understood through forest transition theory or the environmental Kuznets Curve. As well as these positivist analyses there are also the insights developed in pursuit of the normative ideals of foresters as they formulated ideas of optimising wood yields and other welfare from forests with multiple-use approaches. As these approaches seek to embrace more sophisticated policy outcomes than one that is uni-dimensional (single value or use) new debates have emerged about how to reconcile tensions over the best use of forests. The land sharing and land sparing models approach this problem by seeking to optimise outcomes, as does exploration of the related plantation conservation benefit. Leakage analysis seeks to define the gap between policy goals and outcomes in the complex systems being reviewed.

Theory focusing on the role of technology was then examined. Technology is of particular importance to understanding the wood sourcing transition because of its role as an agent of change. In particular, it is a source of change that is, on the one hand, stochastic, in that system-altering technological innovation or its system-wide implications can be unpredictable. On the other, there are also patterns of technological change, such as ongoing improvements in plantation productivity or wood use efficiency, that appear as trends with a predictable quality. Technology also plays a critical role in economic analysis. While it is often considered exogenous to basic market analysis it becomes important in understanding evolutionary change, as seen in the wood sourcing transition—where it is very much endogenous.

Actor-network theory's distinctive approach to treating the social, discursive and natural in complex systems (networks) provides a helpful framework for undertaking a multidisciplinary analysis of the complex adaptive systems that are considered in this thesis. Similarly, resilience thinking provides a useful point for the exploration of how the wood/forest socio-ecological system forms into particular basins and changes to other basins as part of the wood sourcing transition. Broadly, the wood sourcing and forest use transition is one that reflects change in land use patterns, technologies and social institutions. It can be analysed and described by changes in all these three dimensions—and how they interact with one another. The conceptualisation of states of integrated biophysical and social systems and their study as a whole is valuable in framing what is studied here, something that, arguably, both actor-network theory and resilience thinking might support. However, resilience theory seems to particularly lend itself to considering whole systems and how they move from one state or condition to another, while actor-network theory works by studying the 'actant' within the context of its system (network). For this reason this thesis used resilience thinking in particular as a key conceptual tool in seeking to understand change in wood/forest socio-ecological systems.

The preceding chapter touched on a broad range of bodies of intellectual endeavour aimed at explaining how these systems develop and operate. It is clear that they cross over. For example, resilience thinking provides a place where the path-dependent nature of technological processes can be considered in relation to social systems, as it can explain systematic resilience and transformative capacity (or fragility). Resilience theory too, has, as it has developed, come to better incorporate the feedback complexities of the social actors in its social ecological systems.

Finally, reflexive modernity becomes useful in understanding the transition of wood production into cultivated wood systems and the shift of forest management to forest ecosystem management systems. The institutions of stewardship forestry have emerged in and been immersed in key characteristics of modernity: rapid technological change, capitalist and industrialist economies, a pre-eminence of rationality and reason, the nation state. Reflexive modernity is useful both as a guide for how the work of others is understood in this analysis, but also as a guide for how to conduct the analysis, how the writing of this thesis will itself be an act of reflexive modernisation. In particular, the emergence of reflexive modernity within the risk society points to the need for resolution of these conflicts through risk negotiation. Appeals to higher authorities are limited in their ability to reconcile these tensions alone. The work noted above recognises that the making of choices in an environment of political contestation and negotiation is key to resolving tensions between understandings and values acting on the socio-ecological systems of study.

4 The evolution of forest use and wood sourcing—a model

> *There is no such thing as an optimal state of a dynamic system* (Walker, Salt, and Reid 2006).

The two previous chapters have provided an overview of the evolution of transitions in forest use and wood sourcing through both an environmental history and a review of related theories. The following section is a description of a basic model of the transition in wood/forest socio-ecological systems. It has been heuristically derived from the analysis in Part 2. It reviews a number of state variables of the wood/forest socio-ecological system—land use patterns, technology and institutions. The description of these draws on the preceding 2 chapters and summarises their findings. It also describes a process which appears to be replicated across regions and countries around the world, as well as being observable across the world system.

Wood production is undergoing a fundamental shift. As noted earlier, this shift is analogous to the evolution of agriculture emerging from earlier methods of food sourcing from natural ecosystems. At the same time, demand for non-wood ecosystem values from forests is growing due to increasing appreciation of their value, thereby forcing significant change in wood/forest socio-ecological systems.

In order to describe these changes, this thesis draws on a body of work, the resilience thinking described earlier. The application of resilience thinking to natural resource regimes has been used in marine ecosystems and fisheries (Young 2010), water management (Herrfahrdt-Pähle and Pahl-Wostl 2012), and forestry (Rist and Moen 2013). Here, observed changes in wood/forest socio-ecological systems are used to heuristically develop a descriptive framework for these changes.

The thesis postulates the emergence of a clear divergence of wood production and forest ecosystem management systems from previous basins where they were intimately entwined. It uses the metaphors of ecologically derived resilience thinking to define a global process of change that is of major import. As applied in this thesis, resilience thinking offers a chance to tell a complex story, such that existing challenges in forest use, wood production, conservation, governance and policy can be reassessed. It also allows comparison between adaptation and transformation as alternative responses to pressure on existing systems.

4.1 A model of change

The following is a heuristically derived model of four distinct basins that occur in wood/forest socio-ecological systems (Figure 7). Wood/forest socio-ecological systems occur wherever societies interact with wood and forests. The basins as described have been located widely, historically and geographically. Different basins can also exist in different parts of the same jurisdiction or regions at the same time.

As noted earlier the idea of evolutionary or development phases in wood/forest socio-ecological systems has been previously explored (for example, Hyde 2012; Kimmins 2002; Lane and McDonald 2002). A feature of these analyses is a focus on forest use and wood production as integrated activities. However, this model suggests that shifts in wood production from natural forest extraction to cultivation mean wood production and forest use can become geographically and institutionally distinct. This thesis focuses on the stewardship forestry basin in particular, due to its global dominance in the last century. It seeks to address key tensions within this basin through recognition of the emerging transformation into new basins.

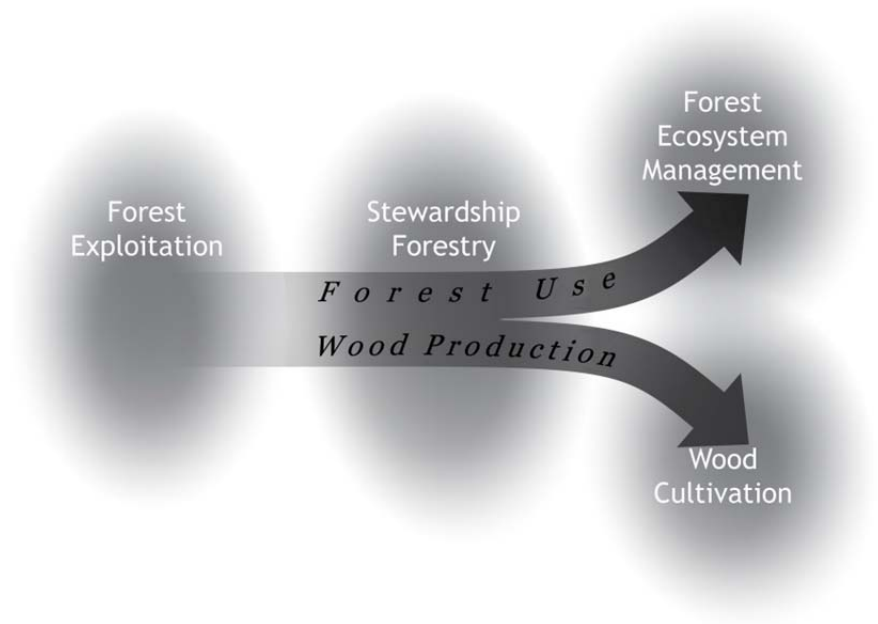

Figure 7. Evolving and diverging basins of attraction in wood production and forest use socio-ecological systems.

The first basin—forest exploitation—involves the opportunistic taking of wood found in naturally regenerated forests. This has occurred both as part of the conversion of forest to agricultural land and as taking of wood alone. The next basin—stewardship forestry—comes about as wood exploitation and conversion for agricultural land cause wood to become less available. Actors respond by developing institutions that control access to remaining forests, and, combined with study of the forest and imposition of restrictions on natural forest logging, they aim to achieve sustainability (specifically of wood supply). In the last 200 years this occurred through the social institutions referred to as 'forestry' (see Vogt et al. 2007, pp. 18-21; Wiersum 1995). This basin sees 'wild' and extensive naturally regenerated forests on frontiers become *managed* and *owned* forests.

In time, economic and technical pressures lead to the application of increasingly agronomic models to tree growth, creating regimes of wood cultivation more akin to agriculture. This takes forms such as wood plantations, crop trees, agroforestry, and trees outside forests. It is described here as the wood cultivation basin. At the same time, in response to increased societal demand for a broad range of other social and ecosystem values, management of natural (and semi-natural) forests becomes increasingly concerned with the delivery of non-wood values. As wood production moves into the wood cultivation basin, a basin of forest ecosystem management emerges that no longer has wood extraction as a central concern (or a concern at all). Figure 7 illustrates the progressive development of these wood/forest socio-ecological systems.

There are distinctive patterns of land use associated with each of the described basins of wood/forest socio-ecological systems. These patterns are not necessarily static within a basin. The forest exploitation basin in particular can involve a pattern of shifting land use as wood extraction follows a receding frontier. Some human societies have been able to live in this basin in a degree of stability. However, emerging agricultural and industrial societies have typically been characterised by growing population densities and a consequent growing wood demand that is generally greater than a fixed area of surrounding natural forest has been able to supply, thus requiring a geographically dynamic process of progressive forest frontier exploitation (for example, Diamond 2005; Simmons 2008; Williams 2002). The impact of this pattern is reflected in declines in global forest extent and quality (Matthews 1983; Pongratz et al. 2008).

The unidirectional nature of forest and land use change in the forest exploitation basin, and its inherent unsustainability in the face of population and technological change, leads to crises that catalyse the development of stewardship forestry. The stewardship forestry basin is characterised by aiming to achieve stability of forest extent and its wood production capability. Extant forest is often made the property of sovereigns and nations, with active protection through regulated use and access and the establishment of forest ecosystem management bureaucracies, as well as allocation of forest to private ownership and the development of regulatory limitations on these (Williams 2002). Changes in global biomass loss reflect shifts in forest use from forest exploitation to stewardship forestry—from 1700 until the 1960s land conversion for agriculture was the largest source of global biomass loss, but since that decade wood extraction has become the largest as it grew while agricultural land expansion slowed (Hurtt et al. 2006).

Over time, additional demands for the management of non-wood values such as water catchment health, recreation, biodiversity and climate stabilisation have led to pressure for change in the forest stewardship basin, as it increasingly struggles with tensions between wood production and these demands. In part, these tensions have been addressed by re-assigning forest from wood production to other land tenures (for example, national parks). Resources are placed into managing forests for recreation and conservation. Reflecting this, the global protected area estate grew exponentially over the twentieth century (Ervin 2003). The area of forests in protected areas grew from 441 million hectares in 1990 to 651 million hectares in 2015 (FAO 2015b). While these shifts are occurring in the allocation of extensive forested lands there is also a shift to intensified wood production on relatively concentrated areas of land. Intensification of wood production through active forest regeneration and management to optimise favoured species and wood production can be seen as an adaptive response within the stewardship forestry basin, but also a move towards transformation to wood cultivation that is essentially agricultural in nature.

Overall, the pattern of land use in wood/forest socio-ecological system basins of attraction follows this trajectory: in the forest exploitation basin, once societal change leads to population and technological growth, there is a continuous shift of deforestation and degradation to new areas of forest; the stewardship basin that follows is characterised by imposition of control, the cessation of forest loss and regulated wood extraction, forest use and regeneration; then a growing pressure to optimise competing demands between wood production and other forest values, along with economic and technological responses, lead to land use specialisation, with wood production focused in smaller areas of intensive wood cultivation and extensive areas of natural forest allocated to non-wood values.

The specialisation of forest use can be a logical outcome of optimisation of the competing demands on forests and land (Vincent and Binkley 1993; Vincent and Potts 2005; Zhang 2005). In addition, as noted above, there are economic incentives to reduce the costs of wood and wood products. In the latter half of the twentieth century parts of logs that were once wasted were increasingly used in products such as pulp, energy, and reconstituted timber products (McKeever 1997; Meil et al. 2007). Ajani (2011b, p. 53), refering to the 'uncoupling of wood [production] from finished wood products through wood saving', uses the example of international paper recycling markets contributing to more efficient use of global pulp log supplies. This pattern is replicated around the world as technologies are shared across jurisdictions—feedback effects across the panarchy. These not only allow greater use of the extracted log but relate to shifting log production from that of stable, slow grown large logs (more commonly found in natural forests) to fibre-rich, fast grown and uniform smaller logs (produced through wood cultivation). Together, this induced innovation, both in how wood is used to make wood products and in how it is grown and harvested (Binkley et al. 2005), is an ongoing source of tension within wood/forest socio-ecological system basins. The process is well understood to disrupt (transform) economies out of equilibrium (resilient or stable states) (for example, Boulding 1981; Nelson and Winter 1982).

The emergence of growing demand for non-wood values from forests also acts as a pressure point for technological change in wood cultivation. Binkley (2003,

p. 4) says, ‘there is no limit on demand for environmental services’ and, compared to wood production, ‘few, if any, technical substitutes’. This increasing demand for social and ecosystem values from forests, along with other land pressures resulting from population and economic growth, raise land costs and push technological and capital substitution towards intensification of wood sourcing from wood cultivation (Binkley 2003). Though natural forests can have a cost advantage through the lack of establishment and growing costs (Oliver and Mesznik 2006), productivity from wood plantations outstrips that of natural forests by an order of magnitude (Paquette and Messier 2009). The productivity of extensively managed forest areas is constrained by increasing environmental regulation (Binkley et al. 2005, pp. 62-3), slow natural forest regeneration rates and reductions in productivity following first harvests (Putz et al. 2012). Wood plantation productivity rates, however, are continually growing through technological improvements (see for example Gonçalves et al. 2013; Mead 2005b; O'Hehir and Nambiar 2010). Wood plantations offer a number of economic advantages in wood production and processing such as log size consistency, greater production concentration near processing and much more efficient use of land. Finally, however, it is important to note that technology can also play a role in system stability (resilience or resistance) as an attractor in the system, especially where complex and expensive new technologies require capital intensive investment (Hyde 2012) or develop associated resistant institutional arrangements such as distributional coalitions.

The role of actors and their institutions are central to socio-ecological system resilience and transformability. In the basin of wood exploitation local communities and wider societies exploit wood from the endowment of accessible natural forests. This phase of unsustainable exploitation can be accompanied by the problems associated with commons (Hardin 1968) and subsequent social turmoil and even collapse in some cases (Diamond 2005). The alternative to collapse for a society dependent on forests is the exercise of restraint in use of the resource through the creation of new social institutions. For wood/forest socio-ecological systems these are the institutions of 'forestry' and can include forest controls, dedicated bureaucracies and the professional forester. They are credited with steering rural communities and remaining forest areas through industrialisation in relatively good shape (Kennedy, Thomas, and Glueck 2001), as well as having established the principles of sustainable natural resource management well in advance of its more general uptake in the late twentieth century (Wiersum 1995). Conversely, as noted earlier, the association of forestry with structures of political power has at times attracted criticism for being party to colonial dispossession and oppression (Bryant 2002; Guha 2000; Peluso and Vandergeest 2001).

Stewardship forestry's 'underlying logic' of sustainable wood production from forests is essentially economic (Nelson 2013). It has been established to manage 'forests and other ecosystems to dampen disturbance cycles to generate a predictable and stable supply of services' (Kant et al. 2013, p. 5). The stewardship forestry basin has been underpinned by this concept of sustainable yield and its inferred condition of an optimal state. However, delivering this is challenged when other levels of the panarchy or state variables of the wood/forest socio-ecological system continually change (for example, social values or technologies). There is a gap between the forester's models of stable equilibrium biological systems and the directional and evolutionary nature of changes to these other dimensions of the wood/forest socio-ecological system (Kant 2000). Further, the emphasis on stock-and-flow optimising approaches can lead to a blindness to the complexities of the systems involved (Norgaard 2010).

Nelson (2013) notes the religious quality of the underlying 'philosophy'[23] of forestry thinking—a widespread belief in the powers of science to guide rational management of resources for the betterment of humans that developed in the late nineteenth and early twentieth century. Nelson argues that as this belief system began to be challenged in the second half of the twentieth century a new set of beliefs began to take hold within which nature was seen to have a value independent of its utilitarian values. The perspective expressed itself in the development of the wilderness inspired conservation movement that in turn evolved into the ecology/biodiversity conservation movements. This new set of beliefs impacted on the conduct of foresters and forestry institutions (in the stewardship forestry basin) but also saw the emergence of the field of biodiversity conservation (the forest ecosystem management basin).

Two distinctive and evolving pressures, as noted above, are operating on the stewardship forestry basin to increase its precariousness and set up the need for adaptation or even transformation. First, there is the global trend toward increased demand for non-wood values from forests. The social drivers for this are complex and multifaceted although clearly of growing international significance (Dunlap and York 2008). Second, there are the economic pressures pushing for ever cheaper and more efficient wood use. The constitution of 'sustainable yield' across extensively managed areas of natural forest in the face of these changing contexts is difficult to achieve (Laband 2013). These pressures increase the complexity of forest management in the stewardship forestry basin, as they bring new and more demanding actors into the space (Kant et al. 2013).

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[23] See also Duerr and Duerr (1975) for a discussion on the role of 'faith' in forestry.

To some extent these tensions are reflected in shifts within the institutions of forestry. Approval of the 'doctrine of timber primacy' amongst US foresters over the course of the first seven decades of the twentieth century shifted from relatively high approval to increasing disapproval (Duerr and Duerr 1975). A shift of forestry focus from purely wood supply to multi use and ecosystem service delivery has been noted (Nelson 2013). There have been declines in enrolments in forestry courses in recent decades in many countries (Leslie, Wilson, and Starr 2006) due to perceptions that forestry is an industry in decline, negative views developed through public conflicts over forestry, and shifting educational resources to training land managers focused on forest ecosystem management (Ferguson 2012). Indeed, Kennedy, Thomas, and Glueck (2001, p. 93) argue that in response to the transition of rural economies in industrial societies to 'urban, post-industrial global societies' there is a need for an evolution of 'foresters managing forests for the public to… natural resource professionals who manage public forest ecosystems with the people'.

The tensions between approaches of adaptation or transformation can also be seen in attempts to define *forests*, *forestry* and *foresters*. In an influential paper addressing the need for clearer definitions of forest types Carle and Holmgren (2003, p. 2) state: '[t]he broad agreement from recent definitions [sic] processes is that "Forests" are tree covered areas not predominantly used for purposes other than forestry'. Here *forests* become defined by the presence of a set of social institutions, *forestry*, and actively exclude tree covered areas that do not have this activity involved. The act of definition becomes more about staking a conceptual claim for the legitimacy of foresters and forestry than it is about forests, trees or even forest ecosystems *per se*. This conceptual confusion can also be seen when Vanclay (2007, p. 885) says the *forester* 'manages ecosystems characterised by trees', and that what distinguishes *foresters* from *agricultural scientists* is that the latter ‘tend to manage resources at paddock scale for an annual production cycle’. By this logic agricultural scientists who deal with non-perennial crops and cropping systems dominated by trees (such as fruit orchards, viticulture, and tropical agroforestry crops such as spices, rubber and palm oil) would be *foresters*, but it is doubtful whether this is what Vanclay had in mind.

These semantic slips are important because they highlight the breakdown in the underlying logic in the stewardship forestry basin. The wood-forest nexus is broken, and this points to a need for institutional transformation. Such a shift is not without precedent—Peluso and Vandergeest (2001, p. 769) observe that in late colonial Southeast Asia, rubber, quinine and coffee were ‘removed from the foresters’ jurisdiction’ and subsequently ‘defined as “agricultural”’. But what is at stake here is more fundamental: do the central institutions of stewardship forestry, including the role of the professional forester, continue to exist if wood production becomes essentially agricultural? This thesis will return to this question.

4.2 Discussion

The above section outlined a model of change in wood/forest socio-ecological systems, and discussed the case for these basins and their underlying logic. However, there are also limitations in the extent that this model can be extrapolated to all circumstances globally. The three case study countries studied in Part 3 of this thesis were initially selected, in part, to describe a range of states in the basic transition of wood production from natural forest exploitation to plantations. But it has become clear that there are other countries where this process might have occurred differently. In particular, there is the case of some European countries where the forest exploitation basin was so progressed that the stewardship forestry basin developed around a type of active reforestation in some ways more akin to the wood cultivation basin, rather than a management of extant natural forest ecosystems.

The following section takes a closer examination of the model and some of its limitations. It does this through a review of factors of significance that influence the rate of change and nature of change between the basins. These factors have been broken into two groups—historic and geographic—shown in Table 1.

Table 1. Significant factors effecting change between basins of wood/forest socio-ecological systems

	History **(Distinctive by time)**	**Geography** **(Distinctive by place)**
Factors	1. Position in power relations/economic 2. Social values of forests 3. Technology	4. Nation state 5. Unique cultures 6. Forest characteristics

The point in history in which the transition in a particular place occurs is likely to influence how it occurs. The larger social, cultural and technological systems (the panarchy) within which the wood/forest socio-ecological system in eighteenth century Germany sat were very different to those of the wood/forest socio-ecological system in, say, Myanmar, at the end of the twentieth century. A country's wealth and development status, the relative role of forestry in its economy, levels of urbanisation, and the relation of society to its forests, and mixes of indigenous/invader societies could also influence the process of basin resilience and transformation responses.

So, the point in history when conditions arose for the emergence and maintenance of a particular wood/forest socio-ecological system is an important factor in how the basin and the transition process occurred. One potential limitation of the three national case studies is that they are all countries established as colonies of European powers (Indonesia primarily by the Netherlands and Australia and New Zealand by Great Britain)—it should be noted, though, that there are only a few parts of the world that were not subject to this process. It is notable that all three of these case study countries were subject to the importation of European ideas about forest management through colonialism and the more general spread of modernity. However, as noted earlier, these ideas were initially developed in parts of Europe after the exploitation of forests was almost total, and in a time when there was little or no social demand for biodiversity, conservation or ecological sustainability. The 'forests' that the original German foresters managed were largely forests of their own planting (Evans 2009). The developing silvicultural practices were all about the growing of new forests for wood production. This was quite different to its subsequent application to the extant natural forest ecosystems of colonised parts of the world. Unlike the situation in Europe, these practices were brought to newly emerging colonial nations and could be applied to still-extensive stands of existing forest. A sensitivity to the potential of forest loss, and both the need and possibility of being able to manage extant natural forests for sustainable wood production, was recognised and allowed for the application of forestry practices that originated in Europe in response to quite different conditions. Thus, learnings from one part of the world system were able to influence the development of wood/forest socio-ecological systems in different ways in other parts of the world. Within the basic model of change described this gives these European wood/forest socio-ecological systems an almost unique position.

A further distinction can be made between the early globalisation of forestry through colonialism and the post-colonial dissemination of forestry institutions through globalised institutions, such as the FAO, often through the guise of development assistance. In turn, countries such as Australia and New Zealand, began exporting forestry expertise to developing countries in the second half of the twentieth century.

This process of dissemination is important not just for its historical application but also for how it reflects on questions of political power. The idea of forestry as a tool of territorial control is covered further in Chapter 7, the Indonesian case study. It has also been noted in places such as India, the US and others. This observation of forestry as a tool of colonialism and territorial expansion and control is not limited to stewardship forestry. There is a considerable body of work observing similarly about the newer basins of forest ecosystem management (for example, in relation to carbon storage in forests, see Wright 2011), and wood cultivation (Casson 2004). As well as being an instrument of territorial control, this imposition of new patterns of land-use can also facilitate the colonisation of ideas and values.

Another historical panarchy factor is the influence of social values on forests and how they might push for change within a system. The development of environmental awareness and subsequent influence on forest use systems was a notable feature of the late twentieth century. Further, it was particularly influential in developed countries, from where it has been extended globally (mush as scientific forestry has been) in what some authors have labelled 'environmental colonialism' (Agarwal and Narain 1991; Nelson 2003). This can be seen as an extension of the developed core's ongoing colonisation; it can also be seen as a logical extension of an emerging global environmental awareness within which it is now understood that actions in one place or country can have effects well beyond specific borders. A feature of this awareness is recognition of the interconnectedness of systems—a recognition that actions in one part of the world can have consequences beyond one's own area and that actions by others elsewhere will have effects on one's own. The logic of this insight will be conducive to action beyond any country of immediate concern to other parts of the world. That is, countries anywhere can be subject to the emergence of a new condition arising within another part of the world system.

Technology is another historical/temporal influence on the development of wood/forest socio-ecological systems. The rapid expansion, peaking and decline of forest exploitation in developing countries using modern logging technologies has already been noted (Shearman, Bryan, and Laurance 2012). The spread of silvicultural techniques around wood cultivation has also been noted. This factor is important. As an example, the range of options for a country like Indonesia to import technical expertise for establishing acacia pulp plantations is considerably greater in the early twenty-first century, where it can draw from a global pool of expertise, than would have been available in the sixteenth century when teak plantings were developed in Java. A polity can, then, potentially transit into new basins much more quickly. It also potentially sets up the conditions for countries to even jump stages.

Overall, technological changes tend to act as a stressor that shifts the wood/forest socio-ecological system from forest exploitation, through stewardship forestry, to wood cultivation basins. What is less clear is whether technology acts as a causative agent. In theory technological innovation is induced from some gap between demand and supply. Nevertheless, technology as applied to wood harvest, processing and cultivation is strongly influenced by technologies developed in other fields and other socio-ecological systems. For example, the development of chainsaws and motorised haulage vehicles in significant part was possible due the development of technologies in areas unrelated to wood production or forests. However, these have acted on the wood/forest socio-ecological system in profound ways. Similarly, the development of screens and electronic data storage systems in information technologies has had a significant effect on global paper demand and, hence, wood/forest socio-ecological systems, despite its development being largely driven by factors outside the wood/forest socio-ecological system. An increasingly integrated global society allows for strong and rapid cross fertilisation of technological ideas and impacts. In the case of forestry, the technologies of forest management developed particularly in the conditions of eighteenth century Germany, yet ended up widely applied around the world. They had a unique spatial and temporal origin but in fact they appear a logical response to conditions that have subsequently arisen in many other places and, once developed, were readily adopted wherever they could be usefully applied. Conversely, they have impacted on different systems, such as those with extensive natural forest still in place, in unintended ways.

These temporal (historic) factors are significant influences on how the model of change plays out. The three main considerations here are the timing of wood/forest socio-ecological system development in relation to three global phenomena: the emergence of a world system of power relations (and its developmental stages), the rise in the late twentieth century of an ecological consciousness and a pursuit of non-wood values in forests, and the level of technological development available to a wood/forest socio-ecological system at the time of other key changes in the socio-ecological system.

The other suite of factors that will influence the basins and the impetus for change between them are geographic. Three main geographic considerations are noted here: biophysical, cultural and economic. They each act as a factor and in addition are modified by each other.

Somewhat related to the influence of the colonial development of the globe was the development of the nation state. It is in the context of nation states as core units of power in the world system that the logic and aspiration of national self-sufficiency in wood production emerges. This can be about security. Not being beholden to another nation's wood supplies and having some certainty of supply of wood, a material that has often been seen as central to economic development, is important. It is likely that this will push countries that might otherwise have been able to more efficiently import wood by playing to their comparative advantage, to instead continue to invest in stewardship forestry and subsequent wood cultivation programs in order to achieve this self-sufficiency. To a lesser extent this pattern is likely to play out within countries with sub-national jurisdictions also acting to maintain supplies, control costs and support their own wood-dependent economies. The likely net effect of this is a greater level of subsidy and investment in plantation development then might have occurred in a perfect global market that was free of the political concerns of sovereign nation states.

The type of forest is an important factor to consider. There is considerable variety in how forests respond to wood extraction, based on the physiology of the trees, climate, soil, and evolutionary history (including exposure to humans). The forests of New Zealand, while producing some highly valued trees in the early stages of forest exploitation, turned out to be dominated by slow growing species. These never generated growth rates capable of producing large quantities of wood on an ongoing basis. Likewise, the tropical rainforests of the world have largely proved to be slow growing and yielding. This is in contrast to the pine species of the temperate and boreal forests of the northern hemisphere and the eucalypt species of Oceania. Hyde (2012) notes the difference between frontier expansion in temperate forests and tropical areas. Temperate forests are more likely to be dominated by few and similar species where the logging tends to be closer to a clear-cut (removing most of the trees in a single encroachment). Tropical forests in the other hand receive much more selective logging, often in the form of high grading of sequentially lower value species. This geographical feature of wood production was clearly understood by Sedjo and Lyons (1983). They noted the wood production advantages of higher latitude pine forests for natural wood production. However, they saw the emerging potential for new plantations based on exotic species in lower latitudes to be much more productive and therefore likely to shift global wood production to the South.

The importance of ecological considerations is evident in the global spread of two specific groups of tree for wood cultivation—pines and eucalypts. Wood cultivation has been able boost wood productivity through these species, firstly, by utilising the best available species for particular conditions from anywhere in the world, but also often by bringing species into new environments where they have not occurred before and thus do not have indigenous diseases and pests to contend with, further enhancing productivity.

Another geographic factor is economic. Trade in wood is to some extent dependent on the location of wood relative to its markets, and these are largely determined by their history and stages of political development. The forests of Europe were partly affected by the demand for wood to build the growing cities and navies that were required during the period of colonial expansion and their industrialisation. By comparison, the extensive forests of Indonesia's outer islands remained relatively untouched until the later decades of the twentieth century, due to distance from markets and a lack of suitable technologies to access the wood, cut it and shift it to markets.

A third geographic factor is political and cultural. National boundaries are artefacts of history and geography. The nation state and the range and diversity of territory, forest and the population they contain is a factor. Large countries such as China, the United States, Brazil and Indonesia are likely to encompass a range of the basins and processes described here, these potentially occurring in different subregions. This is an important caveat on the usefulness of any description of the wood/forest socio-ecological system at the level of the nation state.

Different values (including distinctive cultural values) played out through national politics are also a potential factor. Japan is a country that, through the second half of the twentieth century, largely imported wood from other countries. At the same time it has developed a large national forest estate that it has protected from wood production for a number of non-wood values (Dauvergne 1997). Thus the country made political decisions to outsource wood production even when its own forests had the potential to supply more wood—in distinctive contrast to the examples of nations pursuing self sufficiency in wood production even when it is not efficient to do so.

These factors are also interconnected. How the political geography of a country's wood/forest socio-ecological system affects the transition will in part be a reflection of the physical and ecological geography contained within its borders and also the historical development of the country. For example, Brazil can simultaneously have an advanced wood cultivation socio-ecological system operating in the Atlantic south east that is based on a history of extensive forest exploitation in an earlier time period, while still having frontier wood exploitation occurring in the Amazonian north. Indonesia, Australia and New Zealand also provide examples of different parts of their diverse and extensive landmasses experiencing wood/forest socio-ecological systems in different parts of the country undergoing changes between states at different times.

The previous section outlines a range of factors that qualify how the process described here has presented in different parts of the world. These are important limitations to the model. Firstly, they provide caution for its application and, secondly, they build an understanding of the process outlined. The implications will be discussed further in the concluding chapters.

The model outlines a process of the transition from forest exploitation to wood cultivation and forest ecosystem management, which to a lesser or greater extent can occur in separate geographic areas. As a process of change it would be possible to consider each of the countries of the world to establish their location within the transition. This would be useful when considering policy, as well as being applied in research in order to better understand various aspects of the wood/forest socio-ecological system. The model provides novel insight into the forest transition. Though often considered from a land-use and economic development perspective, the approach here is to consider the forest and wood socio-ecological systems, their evolution and their forest use patterns (rather than just forest extent patterns). It also allows a particular focus on the role of wood extraction and the significance of the wood/forest nexus in stewardship forestry and how this in turn influences change in wood/forest socio-ecological systems.

Part 3: Transition case studies

Part 2 reviewed the transition of wood production from natural forest extraction to cultivated wood sources. It took a broad historical approach, a theoretical review and concluded with a heuristic model of change describing the transition of wood production and forest use. The following section is an assessment of how this transition looks in detail. This section triangulates the research problem through four case studies and a mix of methods and approaches. It starts at the global level and undertakes a quantitative assessment of the transition. Through a model based on international datasets it attempts to answer the question of the extent of the transition of wood production from natural forest exploitation and management to wood cultivation. Then three national case studies tackle the phenomenon from three different perspectives. Firstly, using perspectives of economics and land use policy of the transition in Australia is analysed through forest and wood production. Second, a political and historic analysis of the development of the basins in Indonesia is undertaken. Finally, the case of New Zealand is analysed using a discourse analysis. It looks at how foresters have spoken of changes in the wood/forest socio-ecological system in New Zealand.

The three case study countries are all globally significant forestry countries Australia and Indonesia are ranked 7th and 8th respectively in terms of area of forest. Between the three countries they have 226 million hectares of the world's forests—over 5 per cent (FAO 2015a). In 2014 they produced 6 per cent of the world's industrial roundwood—rankings; Indonesia 7th, New Zealand 13th and Australia 15th (FAOSTAT 2015). Figure 8 below shows the industrial roundwood production for the three countries over the period 1960-2015 and the portions of plantation and natural forest sourced wood produced[24].

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24 Total industrial roundwood data sourced from FAOSTAT and plantation data from various national sources—see Appendix D for details.

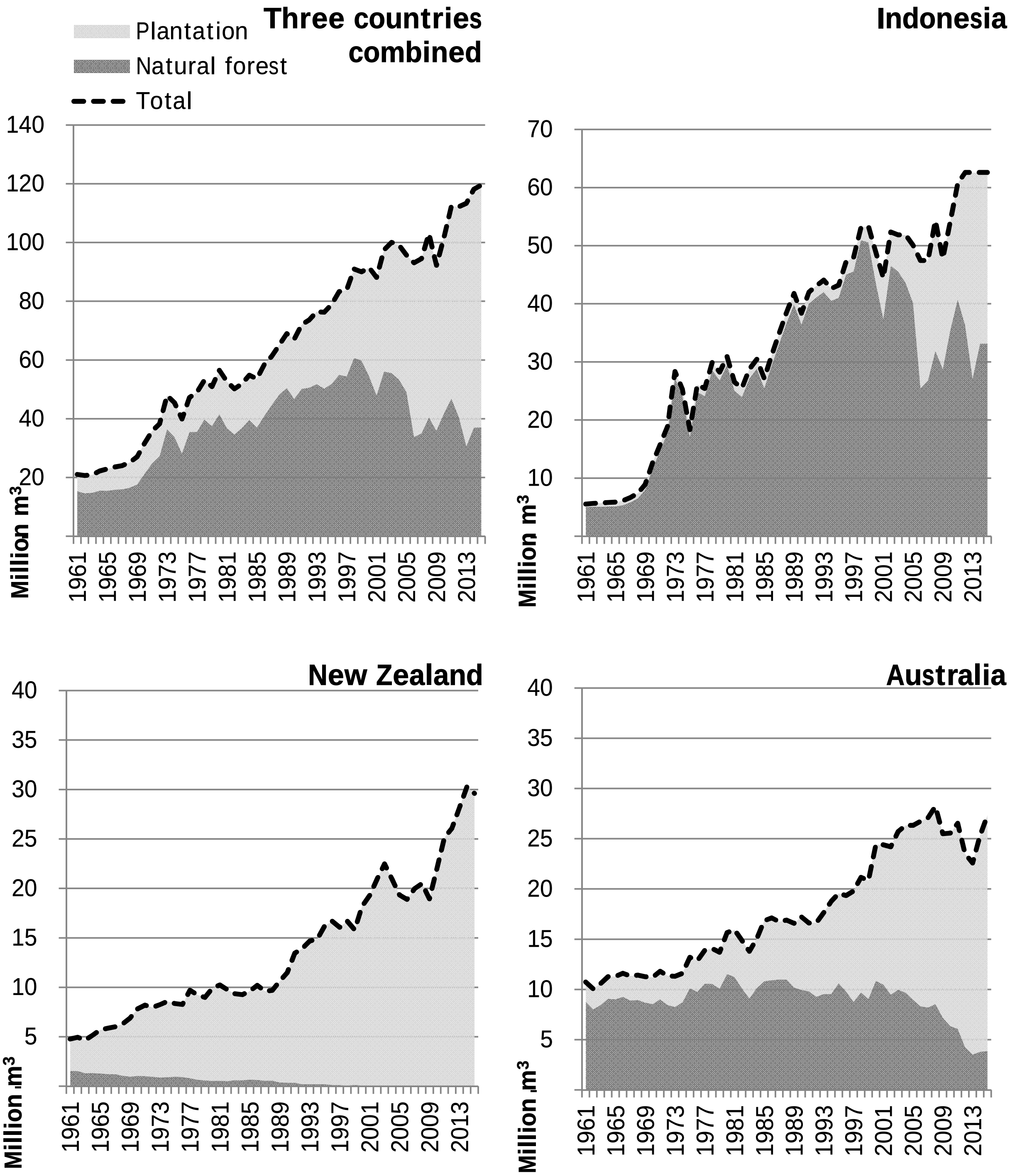

Figure 8. Total industrial roundwood production, plantation sources and natural forest for three case study and three countries combined.

As shown in Figure 8 New Zealand is a country that is 'advanced' in the transition described in this thesis. Its wood production is almost entirely based on plantation sourced wood. Meanwhile, Australian and Indonesia are each progressively less advanced along this path. These latter two countries also present a number of sub-jurisdictions that are at different stages of the transition. Together these cover a range of conditions and states in the transitionary path. The three case studies also encompass both developed and developing economies. In addition they were chosen to take the 'tack' of nature in the case of Australia, society in Indonesia and discourse in New Zealand. While different tacks in each case study limited the scope for comparison, this enhanced the ability to triangulate the phenomenon being researched. In addition to the three critical 'tacks' each country case study used a unique area of focus to which the 'tack' was suited: Australia for land use, New Zealand for technology and Indonesia for institutions.

5 A global analysis of trends in wood sourcing[25]

This chapter seeks to define the extent to which the global wood sourcing transition is actually occurring. An effective understanding of what is taking place needs a global perspective. There are two main reasons for this: firstly, nation states are at different stages of economic development and have widely varying geographies. At the level of individual states (nations and states within nations) there is a wide range of conditions in terms of the current state of forests, their extent, and their use for wood extraction. Choosing to look at any one state or a handful of states is likely to provide a confusing or limited picture. Secondly, the social and economic systems that are operating in each nation interdepend on those occurring within others. Indeed, many aspects of the economy of wood and forest use and trade are international, not to mention such interconnected biophysical systems as water, biodiversity and carbon that operate at this scale. For this reason a global analysis is effective in bounding a system in a way that is more difficult at smaller scales.

A key challenge in past attempts to quantify the international picture of plantation forest trends has been the inconsistency of data. In a review by (ABARE 1999, p. 80) the authors noted that, 'the information available on plantations reflects more on what is *not* known about plantations'. This has been possibly further confused due to the definitional issues noted by Carle and Holmgren (2003). The research presented in this chapter tackles this problem and

[25] The text of this chapter, after the initial quotation in 5.1 closely follows the text that appears in the paper, 'Global wood production from natural forests has peaked', published in *Biodiversity Conservation* (Warman 2014). In the month before finalising this thesis the analysis was updated to reflect an extra three years FAO data that had become available since the paper was written in 2013. Copyright for this material rests with the publisher, Springer.

seeks to clarify as best as possible the magnitude of the pattern of change in wood sourcing from natural forests to cultivated wood.

5.1 Introduction

> *It is thus foreseen that planted forests will increasingly contribute to the supply of the world's wood, fibre, fuel and NWFPs (as well as protecting soil and water resources and fulfilling other purposes) and that this shift may reduce the pressure on natural forests. The impact of this development on timber markets should be considered by policy-makers, planners and forest managers and supported by outlook studies that evaluate the future contribution of planted forests to economic, environmental and social services* (FAO 2010a, p. 87).

As already noted, wood has been a vital natural resource for humans. It has been the primary source of fuel for most of human existence and central to building, tool making, information sharing (in the form of paper) and shipping. Mostly wood has been obtained from naturally regenerated forests, much as food was primarily collected from natural sources before the advent of agriculture. However, in response to local or national wood shortages, there has been an increasing move to intentional wood cultivation, essentially as crops (Simmons 2008; Vogt et al. 2007; Williams 2002).

There is a growing body of evidence pointing to a decline in natural forest wood extraction in many nations, consistent with the 'Hubbert Curve'; a rapid increase in production to a peak followed by a sharp initial decline followed by a slow tapering off (Hubbert 1993). Shearman, Bryan, and Laurance (2012) demonstrate that 'peak wood' has been passed in the Solomon Islands, Philippines, Thailand, Malaysia, Laos and Indonesia. Countries supplying a large portion of China's wood in 2006 were harvesting at unsustainable rates, with only years to decades left to economically access mature natural forest: in the Russian Far East it was 20 years; in Indonesia, 10 years; Papua New Guinea, 13-16 years; Myanmar, 10-15 years; Cambodia, 4-9 years (White et al. 2006). Roundwood production in tropical forests is 54 per cent lower than the first cutting in the second rotation (Putz et al. 2012). Canada's historical industrial roundwood production, largely sourced from natural forests (Kanowski and Murray 2008), peaked in 2004 at 205 million m^3 and in 2015 was 151 million m^3 (FAOSTAT 2016). Australia's natural forest wood production has declined from 10.8 million m^3 in 1999-2000 to 3.6 million m^3 in 2013-2014 (see Appendix 6).

This chapter will assess the global trend in wood extraction from natural forests in order to understand how this will affect the future roles of wood production, biodiversity conservation and other ecosystem services in natural forests. While these roles are strongly influenced by regional and national factors, it is also valuable to understand how any specific local pattern of forest use is influenced by global trends, as well as identifying the likely future trajectories of local and national patterns of forest use that are derived from global patterns. This will be of particular value where wood production competes with other forest use values, and policy makers and managers have needed to 'balance' these competing demands. Finally, global trends also provide data against which the effectiveness of global forest policy and governance initiatives and structures can be measured.

5.2 Methods

In order to assess the global trend in roundwood[26] production from natural forests three key steps were required. Firstly, an estimation of total roundwood production was developed from historical data, along with three outlooks; an upper bound high growth projection, a projection based on best-fit trends of the historical pattern, and an intermediate pattern. Secondly, cultivated roundwood

[26] 'Roundwood' refers to the total wood removed from forests and from trees outside forests.

production patterns for the same period were developed, creating high and low bound scenarios for the two different cultivated wood groups described below. The third step was to subtract the cultivated roundwood estimate from total roundwood to generate the natural forest roundwood production totals. This was done for each combination of total roundwood output and cultivated roundwood output variants to produce four different natural forest roundwood datasets for the historical period, and, reflecting the higher levels of uncertainty, twelve for the forecast period.

The rationale for this method stems from the lack of data on wood extraction[27] from natural forest sources. The Food and Agriculture Organisation of the United Nations (FAO) global datasets on roundwood production include all sources of roundwood: natural forests, plantations, planted forests and trees not from forests. There have also been some analyses of global totals and trends in roundwood from cultivated wood sources (ABARE 1999; Brown 2000; Carle and Holmgren 2008; Smeets and Faaij 2007). Between them—the FAO total roundwood data and cultivated wood analyses—they offer the opportunity to subtract one from the other to derive totals and trends for natural forest roundwood extraction.

For this analysis the historical period back to 1945 was assessed based on the availability of suitable data. The FAO was established in 1945 and global data prior to this period is scant. Projections to 2030 were used as this is a date that occurs frequently in published roundwood production projections. Detailed data

[27] The terms ‘extraction’, ‘production’, ‘supply’, ‘demand’ and ‘consumption’ are all used here in relation to global roundwood. At the scale of the annual global data points used here it is assumed that, as the world is a closed system, the quantities of these will be the same; that is, ‘extraction’, ‘production’, ‘supply’, ‘demand’ and ‘consumption’ will generally match one another.

including specific numbers and supplementary data for graphs shown in this chapter are included in Appendix E.

A number of definitions are important to this analysis: roundwood types and the various roundwood sources, including natural forests, planted forests and plantations. Roundwood is an aggregate of two main subgroups: fuelwood (for energy production, industrial or domestic), and industrial roundwood (all other roundwood types such as pulplogs, sawlogs and veneer logs) (FAO 2010a). These two roundwood types are a key categorisation employed in the FAO's statistics and other sources used.

Definitions of forest and non-forest types draw on work developed by Carle and Holmgren (2003), as discussed in the introduction of this thesis, as part of attempts to understand global trends in cultivated wood development. The definitions developed (Figure 9) have been widely adopted and used, most notably by the FAO. They are used in this analysis to define *natural forest* as those forest types at the natural and semi-natural end of the spectrum; distinct from roundwood sources on the other side of the spectrum, described here collectively as *cultivated wood*. The analysis will use two different sets of cultivated wood, reflecting the data available: one including planted forests, and one with only plantations and trees outside forests.

Forest					Non-Forest
Natural Essentially naturally regenerated		**Semi-natural** Intensive silvicultural assistance in regeneration of primarily native species		**Plantation** Primarily introduced species	**Trees outside forests**
Primary	**Modified**	**Assisted natural regeneration**	**Planted**		
No clearly visible signs of human activity.	Clearly visible signs of human activity.	Activities such as weeding, fertilizing, thinning and selective logging	As for Assisted but also includes planting, seeding and coppicing of specific species	Planting of species for afforestation or reforestation, often as monoculture	Stands smaller than 0.5 ha in agricultural and urban landscapes

Natural forest wood natural + assisted natural regeneration	Cultivated wood (Planted forest) planted + plantation + trees outside forests

Natural forest wood natural + assisted natural regeneration + planted	Cultivated wood (Plantation) plantation + trees outside forests

Figure 9. Continuum of wood source characteristics—modified from Carle and Holmgren (2008)

The following two sub-sections detail the methods and sensitivity analysis applied to the development of the global total roundwood production figures and the global total cultivated roundwood production variants.

5.2.1 Global roundwood production: data and sensitivity analysis

A historical global roundwood dataset for 1945-2012 was developed using data from the FAO. Three future roundwood production outlooks were developed: a high, middle, and low level of projected future roundwood production (Table 2).

Table 2. Summary of total roundwood production data methods and materials

Total roundwood consumption	Industrial roundwood	Fuelwood
Historical record FAO	FAOSTAT (2016) for 1961-2015, FAO Yearbook of Forest Products Statistics 1962 and 1958 (FAO 1958, 1962) for 1948-1960, and linear extrapolation for 1945-47 from the 1948-1960 results	FAOSTAT (2016) for period 1961-2015 and extrapolation based on 1961-2015 trend in per capita fuelwood consumption (population data - United Nations 2011) for 1945-1960
Scenario 1 Historical trend	Extrapolation of best fit trend of 1945-2015 industrial roundwood for 2016-2030	Extrapolation based on 1961-2015 trend in per capita fuelwood consumption (population data - United Nations 2011) for 2016-2030
Scenario 2 Intermediate	Midway point for each year between Scenario 1 and Scenario 3	
Scenario 3 High Growth	Based on FAO (2009) projections for period (1.8 per cent annual growth 2005-2020 and 1.3 per cent subsequent), applied from 2016 onwards	1.3 per cent annual growth from 2016 onwards based on Buongiorno et al. (2012) assuming high future demand for biofuel

All roundwood data (fuel and industrial) for the period 1961-2015 were taken from FAOSTAT (2016). Suitability of the FAOSTAT data for use in this analysis was checked with the FAO Forestry Department. The data are generated from annual country surveys, ‘unofficial’ sources such as trade journals, industry association reports and statistical yearbooks, and FAO estimates for the remainder (including ongoing adjustments when problems such as unreported production are found). The FAO estimates for industrial roundwood are based on previous years’ figures, and for fuelwood by use of methods refined following a review of fuelwood consumption in response to concerns[28] that prior estimates were inaccurate (Whiteman, Broadhead, and Bahdon 2002). A recent internal FAO assessment found that approximately 20 per cent of the global quantity of industrial roundwood and 85 per cent of fuelwood was estimated by these estimate methods. There have been no definition changes that would limit the comparability of the FAOSTAT series data for the period 1961-2015. Overall, the use of the data in this analysis was considered sound (Arvydas Lebedys [FAO, Forestry Department] pers. comm., 22 and 28 September 2013).

Industrial roundwood figures for the period 1948-1960 were taken from the 1958 and 1962 FAO *Yearbook of Forest Products Statistics* (FAO 1958, 1962). Where these sources reported different figures in overlapping years the data from the latter report were used (as advised by the FAO). The period from 1945-47 was derived using a linear extrapolation of the period covered by the published yearbooks (1948-1960). The resulting figure of 605 million m^3 of industrial roundwood for 1945 is consistent with the figure of 600 million m^3 reported by Solberg et al. (1996) from the FAO.

Fuelwood consumption reported in annual reports (FAO 1958, 1962) for the period prior to FAOSTAT data (that is, before 1961) is considerably lower than the FAOSTAT data would suggest. For example, the FAO *Yearbook of Forest Products Statistics 1962* (FAO 1962) fixed global fuelwood for 1961 at 755 million m^3, with figures ranging from 792 to 696 million m^3 for the period 1951-1961. This is out of step with the FAOSTAT figures of 1,498 million m^3 for 1961 and

[28] The three main concerns addressed in the review were: country survey response rates for fuelwood were very low; per capita consumption rates had been considered to be static (though growing evidence contradicted this by pointing to a decline in per capita consumption in response to trends such as urbanisation and wealth increases); and prior estimations did not account for non-household use.

only a very small trend upward in subsequent years—just climbing to 1,550 million m^3 in 1971. The 1962 *Yearbook* notes that 'figures for fuelwood removals are far more incomplete than those for industrial roundwood' and that 'statistics for fuelwood removals are still considered to understate actual removals' (FAO 1962, p. VII). Datasets for fuelwood underwent major revision in 2002 (Whiteman, Broadhead, and Bahdon 2002). Given the FAO's Yearbook's unreliably low fuelwood estimates before 1961, a backwards extrapolation of FAOSTAT data using the exponential trend in annual global per capita fuelwood consumption for the period 1961-2015 ($y = 0.478e^{-0.012x}$, $R^2 = 0.9909$) was used to provide fuelwood figures for 1945-1960.

Totals for global industrial roundwood and fuelwood developed by the above methods were then combined to derive global total roundwood production for the period 1945-2015.

In order to develop a likely range of outlook scenarios a review of past outlooks was undertaken. In the late 1990s considerable effort went into developing global industrial roundwood forecasts. Many of these studies were subsequently found to have overestimated projected production. A failure to sufficiently account for growth in resource productivity has been suggested as a key reason for this (Ajani 2011b; Smeets and Faaij 2007). Two reviews of published outlooks, Smeets and Faaij (2007, p. 13) , supplemented and modified from Weiner and Victor (2000) and ABARE (1999), list between them a total of 37 scenarios with an outlook for 2010 (see Appendix E for details). These were produced by 15 authors between 1994 and 2001. The outlooks for 2010 had an annual mean of 1,961 million m^3, and ranged from 1,510 million m^3 to 2,700 million m^3. The recorded production in 2010 was 1,703 million m^3 (FAOSTAT 2014)—only three of the 37 forecasts were lower than this. Similar patterns of overshoot in industrial roundwood projections are noted in fuelwood projections from the same sources.

Given this tendency for past published outlooks to exceed actual production, projections using best-fit trends of historical data were used to give a feasible low end scenario. In the case of industrial roundwood this was based on historical volumes and in the case of fuelwood it was based on historical per capita consumption trends multiplied by population projections. The validity of the low end fuelwood projections used here is backed by more recent analysis suggesting that stagnant fuelwood use is likely to continue into the future (Arnold et al.; Mead 2005a). The high growth variation for industrial roundwood outlook here uses projected growth rates from the FAO *State of the World's Forests 2009* (FAO 2009), applied from 2016. These rates were 1.8 per cent per annum for 2005-2020 and 1.3 per cent for 2021-2030. As with the earlier projections noted above, this set of predictions (published in 2009) has so far been much higher than actual growth—industrial roundwood grew from 1,786 million m^3 in 2005 to 1,847 million m^3 in 2012 (FAOSTAT 2016), an annual growth of 0.6 per cent—and is therefore considered a suitable, if unlikely, upper bound growth scenario. The upper bound variation for fuelwood was based on a 2030 fuelwood projection developed using the Global Forest Products Model with Intergovernmental Panel on Climate Change assumptions of 'varying but large future biofuel production' (Buongiorno et al. 2012, p.1). This is consistent with other literature speculating that increased future energy demand or climate initiatives will raise fuelwood consumption (FAO 2010b; Heinimö and Junginger 2009). The highest of the three scenarios involved a fivefold increase in the growth rate observed between 1992 and 2006 and was considered unrealistic. The second highest growth scenario was chosen. This involved annual growth of 1.3 per cent. It is considered a reasonable upper bound growth scenario. While the combined industrial roundwood and fuelwood upper bound growth scenario used here is considered unlikely, it gives a conservative test on the impact of possible future growth on the trends in natural forest wood extraction.

5.2.2 global roundwood from cultivated wood: data and sensitivity analysis

Data for cultivated roundwood production were generated from published outlook studies and estimates of trends in roundwood production from these sources. As noted earlier, the distinction between natural forest and other sources of wood is not a neat duality, but rather two ends of a spectrum, with a number of possible points to delineate the two. In recognition of this, four variants of cultivated roundwood were developed: a high and low bound estimate based on productive plantations, as used in Brown (2000), and trees outside forests; and a high and low bound estimate based on the broader category of planted forests, as used in Carle and Holmgren (2008), and trees outside forests (Table 3). Both Brown (2000) and Carle and Holmgren (2008) utilised data collected through international surveys undertaken in conjunction with the FAO. Both sets of work necessarily include a range of assumptions (such as stand age of future harvests, current and future silvicultural methods, and rates of production efficiency gains) that would affect predicted outcomes if they were to change. In all variants, roundwood from trees outside forests was estimated drawing on the work of Smeets and Faaij (2007).

Table 3. Summary of total cultivated roundwood production data methods and materials

Variants	Industrial roundwood and fuelwood past estimates	Industrial roundwood and fuelwood forward estimates	Fuelwood from trees outside forests past and forward estimates
Plantation—low estimate	Brown (2000) Scenario 2 1995 estimate than roughly exponential decline in steps 1990-1995, 1970-1989, 1960-1969, 1945-1959	Brown (2000) Scenario 2 1995-2030 projections	Assume grew from a portion of 1/10 of total fuelwood in 1945 to 1/3 in 2007 and the portion continued to grow at same rate afterwards
Plantation—high estimate	Brown (2000) Scenario 3 1995 estimate than roughly exponential decline in steps 1990-1995, 1970-1989, 1960-1969, 1945-1959	Brown (2000) Scenario 3 1995-2030 projections	Assume grew from a portion of 1/3 of total fuelwood in 1945 to 2/3 in 2007 and the portion continued to grow at same rate afterwards
Planted forest—low estimate	Carle and Holmgren (2008) projected back from 4/5 of 2005 estimate in same linear trend as projected forward from 4/5 of 2005 estimate to Scenario 2 estimate for 2030 until 1990 and then at half that rate from 1990 backwards	Carle and Holmgren (2008) projected up from 4/5 of 2005 level in linear fashion to Scenario 2 2030 level	Same as Plantation—low
Planted forest—high estimate	Carle and Holmgren (2008) Scenario 3 projected back from 2005 estimate in same linear trend as projected forward from 2005 until 1990 and then at half that rate from 1990 backwards	Carle and Holmgren (2008) Scenario 3 projection from 2005 to 2030	Same as Plantation—high

Brown (2000) included three scenarios. Scenario 1 was based on no new plantation establishment from 1995. This has clearly not been the case and it is not used here. Scenario 2 was chosen as a low end case. It was based on a projected growth of plantation area of 1 per cent per annum. Del Lungo, Ball, and Carle (2006) published productive plantation figures (79 million ha in 1990, 99 million ha in 2000, and 111 million hectares in 2005) where annual growth rates were 2.55 per cent between 1990 and 2000 and 2.25 per cent between 2000 and 2005. This is much higher than Brown's 1 per cent for Scenario 2, and consequently this scenario is used in this analysis as the low bound variant. Scenario 3 used the current planting rates of 1995 and extended them until 2004, subsequently reducing them progressively to 20 per cent of the 1995 rate of growth in 2035. This is used as a conservative high bound plantation variant.

The two planted forest variants were adapted from Carle and Holmgren (2008) . Of these, the authors considered Scenario 3 to be the 'most probable scenario until 2030' (Carle and Holmgren 2008, p.15). It is used here as a conservative high bound variant. Scenario 2 is based on the planted forest estate growing in line with past trends but does not factor in the productivity increases of that estate used in Scenario 3. It is used here as a low bound variant. It was modified by reducing the level of the 2005 estimate of planted forest roundwood production by four fifths to give a lower overall planted forest roundwood output than the high bound variant for both historical and outlook periods.

The use of roughly exponential increases in roundwood outputs in the four variants is designed to replicate the historical patterns of plantation and planted forest establishment. Published accounts suggest an exponential pattern of plantation and planted forest establishment, with uptake at a relatively low level in European countries through the later centuries of the second millennia. In the first half of the twentieth century this spread to countries such as Australia, New

Zealand, South Africa and the US. In the last fifty years there has been a dramatic global expansion of plantations, especially in developing countries (Evans 2009, pp. 5-22; Varmola et al. 2005). The FAO notes that 'most of the long term growth in wood supply is occurring in countries that have established planted forests during the last few decades' (FAO 2010a, pp. 86-7 p. 86-87). In 1995 the age class of the world's plantations was heavily skewed to those less than 15 years old, indicating the fast rate of recent expansion of global plantations (Brown 2000). This is consistent with the findings of Del Lungo, Ball, and Carle (2006).

The FAO estimates of total roundwood (industrial and fuel) include roundwood from forests (natural and planted) and non-forest sources such as woodlands and trees not from forests. It is estimated that globally there are over one billion hectares of agricultural land with greater than 10 per cent tree cover that is not formally considered forest (Zomer et al. 2009). This reserve of trees is likely to supply significant portions of the world's fuelwood supply, especially in developing countries where much of the world's fuelwood is consumed. For example, Africa's significant fuelwood consumption may come largely from trees outside forests (FAO 2010a, p. 172). It has been estimated that two thirds of global fuelwood consumption is from trees outside forests (Smeets and Faaij 2007), with 'planted trees on farmland, in villages and homesteads and along roads and waterways contribut[ing] significantly to fuelwood supplies, enabling the demand to be met in most instances' (FAO 2001, p.23). It is likely that the amount of fuelwood coming from cultivated trees is increasing, with plantation and agroforestry planting for this purpose beginning in the 1970s on a large scale in Africa and Asia (Hyde, Amacher, and Magrath 1996). Based on this, two scenarios for the contribution of trees not from forests to fuelwood production were used here. The low bound variants assume a one third contribution to fuelwood at

2007—half of Smeets and Faaij's (2007) assessment of two thirds—climbing from one tenth in 1945 (a negligible base, but assuming some limited contribution from trees outside forests). The high bound variants use a linear trended portion of the annual total, starting at one third in 1945, increasing to Smeets and Faaij's (2007) two thirds in 2007, and growing at the same rate beyond.

5.3 Results

Results presented start with findings related to total global roundwood production, followed by the findings for total global cultivated roundwood production, and finally, the results for total global natural forest roundwood production, derived by subtracting cultivated roundwood from total roundwood.

The first component of the historical roundwood production analysis was the period prior to that recorded in the FAOSTAT data (before 1961). Industrial roundwood production figures for the period 1945-1960 are shown in Figure 10.

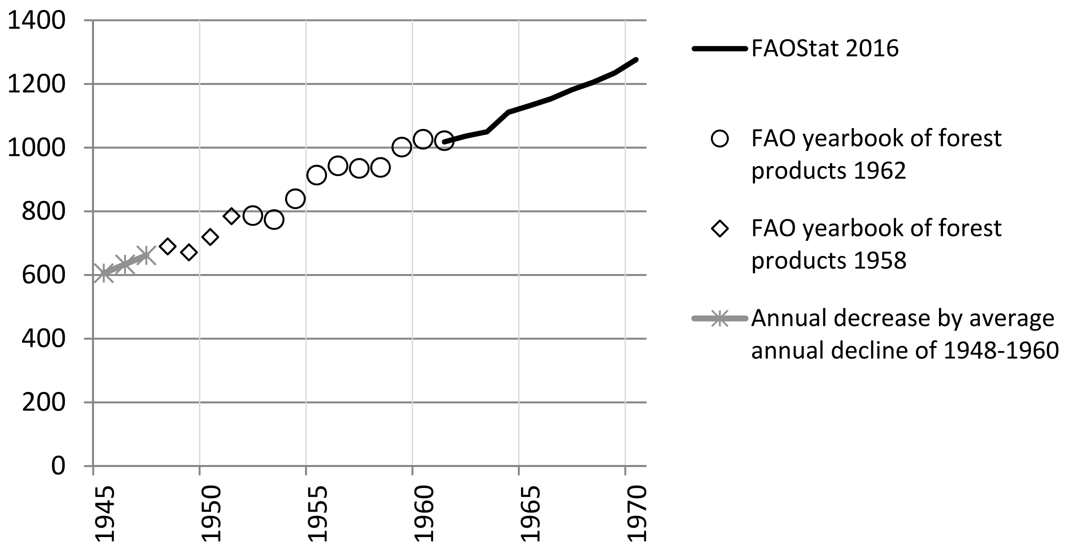

Figure 10. Results for total historical industrial roundwood production 1945-1970

The total roundwood data trend determined for 1945-1960 and shown in Figure 11 was combined with the FAOSTAT data for 1961-2015 to generate a historical record for the period 1945-2015 and is shown as 'Historical record FAO'. Three scenarios of total industrial roundwood outlook for the period 2016-2030 were generated and are also shown in Figure 11. Scenario 1 shows a projection consistent with a best-fit trend (second degree polynomial) for the period 1945-2015, leading to a slow decline in total industrial roundwood production over the coming decades, reaching 1,470 million m^3 in 2030. Scenario 3, as the upper bound, gives a rate of sustained growth leading to 2,174 million m^3 total industrial roundwood in 2030.

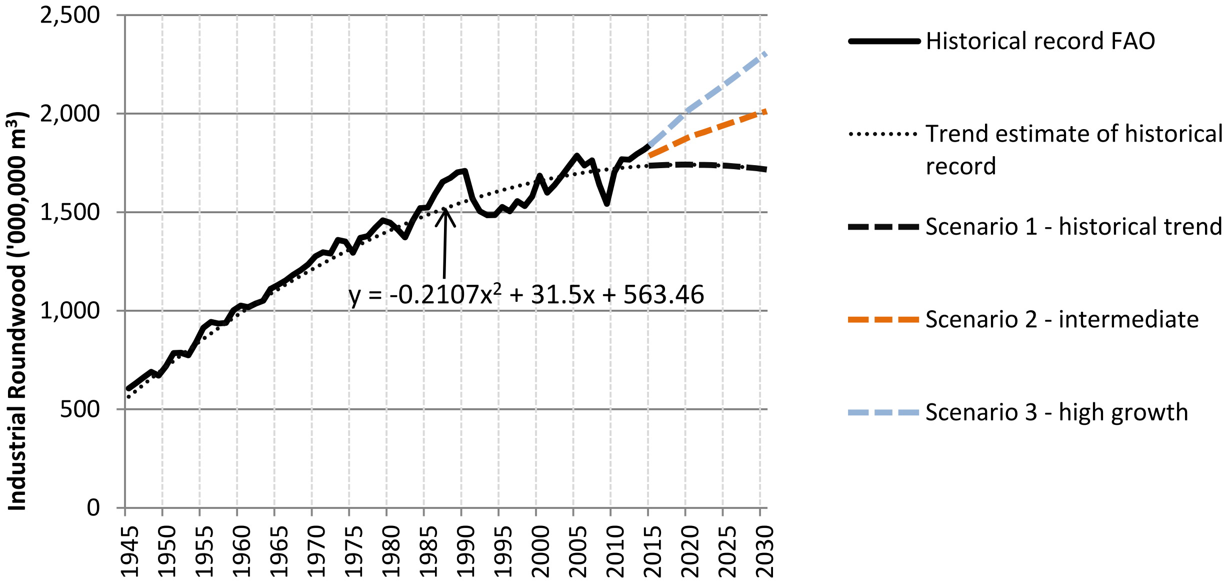

Figure 11. Total industrial roundwood production for historical period 1945-2015 and three forecast scenarios for period 2016-2030

Global fuelwood consumption per capita declined from 0.484 m^3 per annum in 1961 to 0.256 m^3 in 2015. The annual change in rate has a best-fit line that follows an exponential trend ($y = 0.478e^{-0.012x}$, $R^2 = 0.9909$). This per capita use was extrapolated to the years 1945-1960 and 2016-2030, and applied to the United Nations 2010 historical population record to 1950 and a linear extrapolation for

1945-1949 using 1950-1960 rates of change, and the projected population for 2016-2030 using the medium fertility forecast (United Nations 2011). Results are given in Figure 12. These showed an increase in fuelwood consumption from 1,353 million m^3 in 1945 to 1,507 million m^3 in 1960. The high growth scenario, based on possible future increases in biofuel demand in response to rising global energy demand or climate change policy initiatives (Buongiorno et al. 2012; FAO 2010b; Heinimö and Junginger 2009), has an increase in fuelwood consumption over subsequent years to 2,396 million m^3 in 2030.

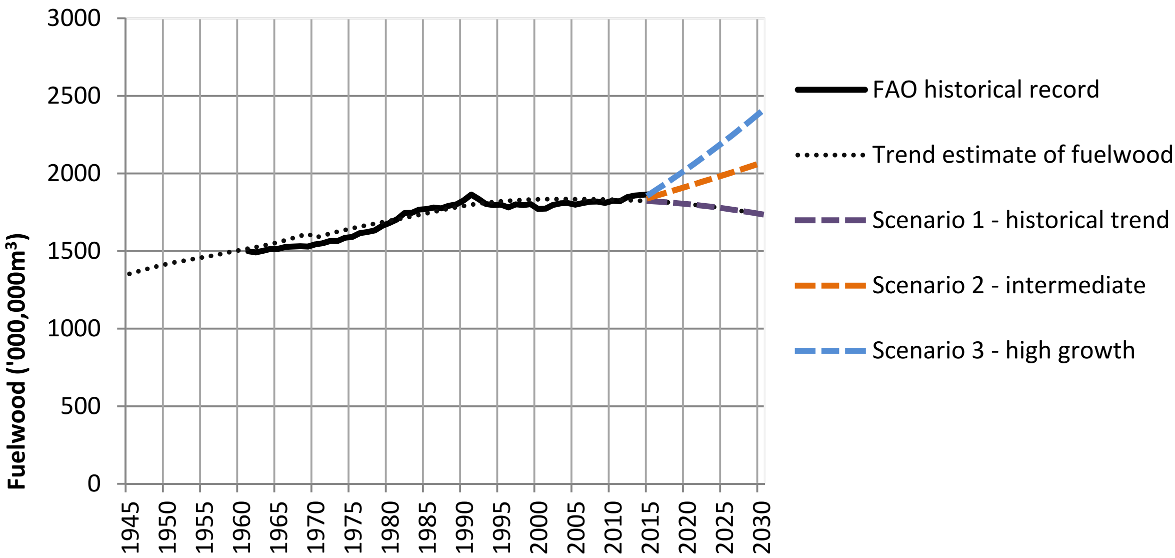

Figure 12. Total fuelwood production for historical period 1945-2015 and three forecast scenarios for period 2016-2030

As noted above, four cultivated wood variants were developed, a high and low bound variant for each of the two different cultivated wood categories: plantation and planted forest (Figure 13). The high and low bounds are through both historical and future periods, reflecting the higher degrees of uncertainty for cultivated wood estimates. The planted forest variants have higher outputs than the plantation variants, reflecting their inclusion of a broader range of the forest spectrum and, therefore, a larger area of forest and production potential.

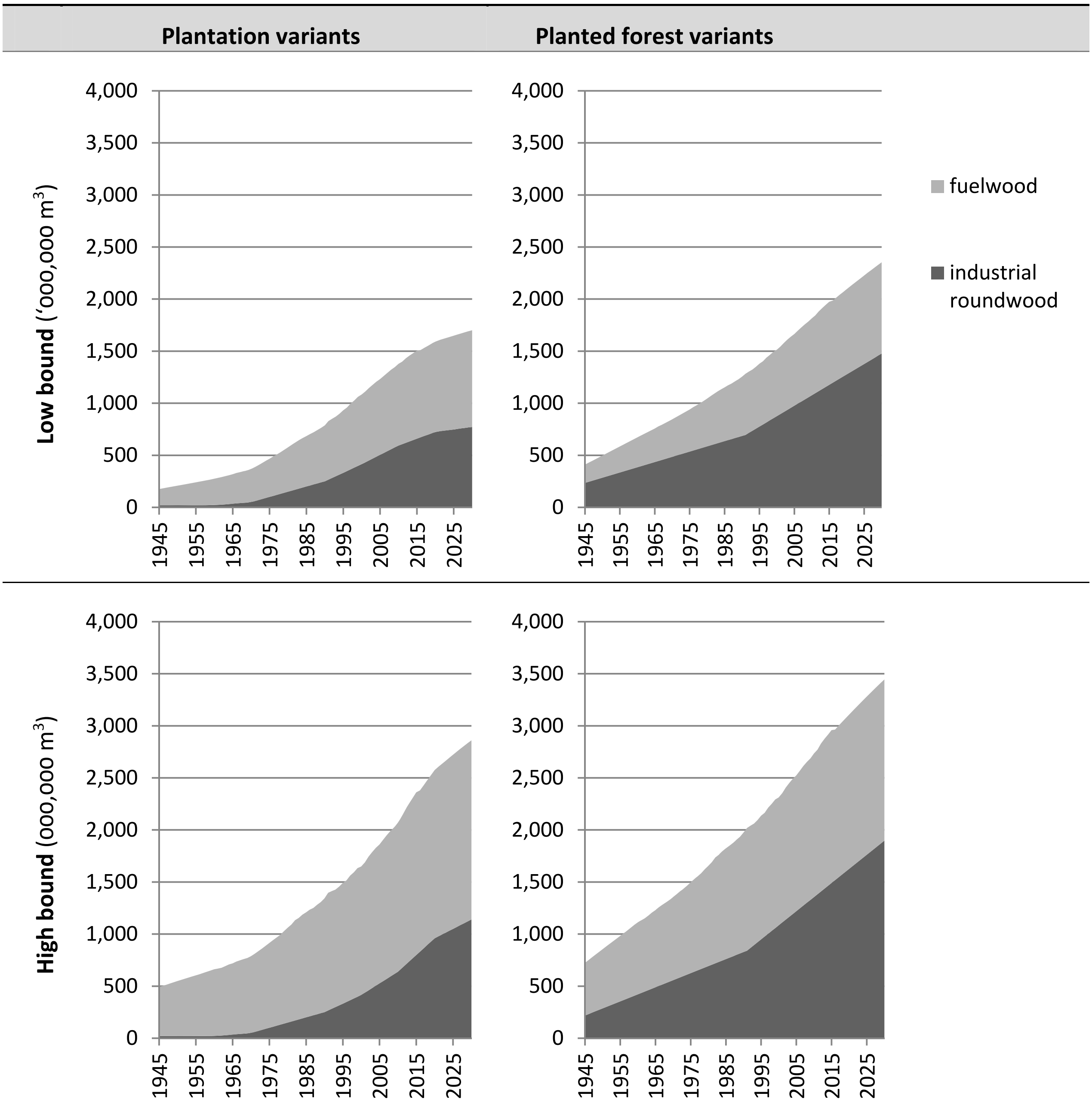

Figure 13. Estimated fuelwood and industrial roundwood production variants from wood cultivation, including trees outside forests

Natural forest roundwood production estimates were derived by subtracting cultivated wood variants from total roundwood production figures. The historical natural forest roundwood estimates (1945-2015) indicate that roundwood production from natural forests peaked in 1989; with a subsequent decline as roundwood from cultivated trees replaced increasing portions of total roundwood supply (Figure 14). Of the twelve future natural forest roundwood scenarios (2016-2030), only two had future roundwood passing the 1989 peak (plantation low bound variant/total roundwood high growth, in 2026 and planted forest low bound variant/total roundwood high growth in 2029). Four other scenarios have natural forest roundwood increasing in the outlook years at rates that would eventually pass the peak year at some point beyond 2030. Six of the twelve future scenarios have natural forest roundwood declining into the future, with natural forest wood extraction almost ceasing altogether by 2030 in one scenario (planted forest high bound variant/total roundwood historical trend).

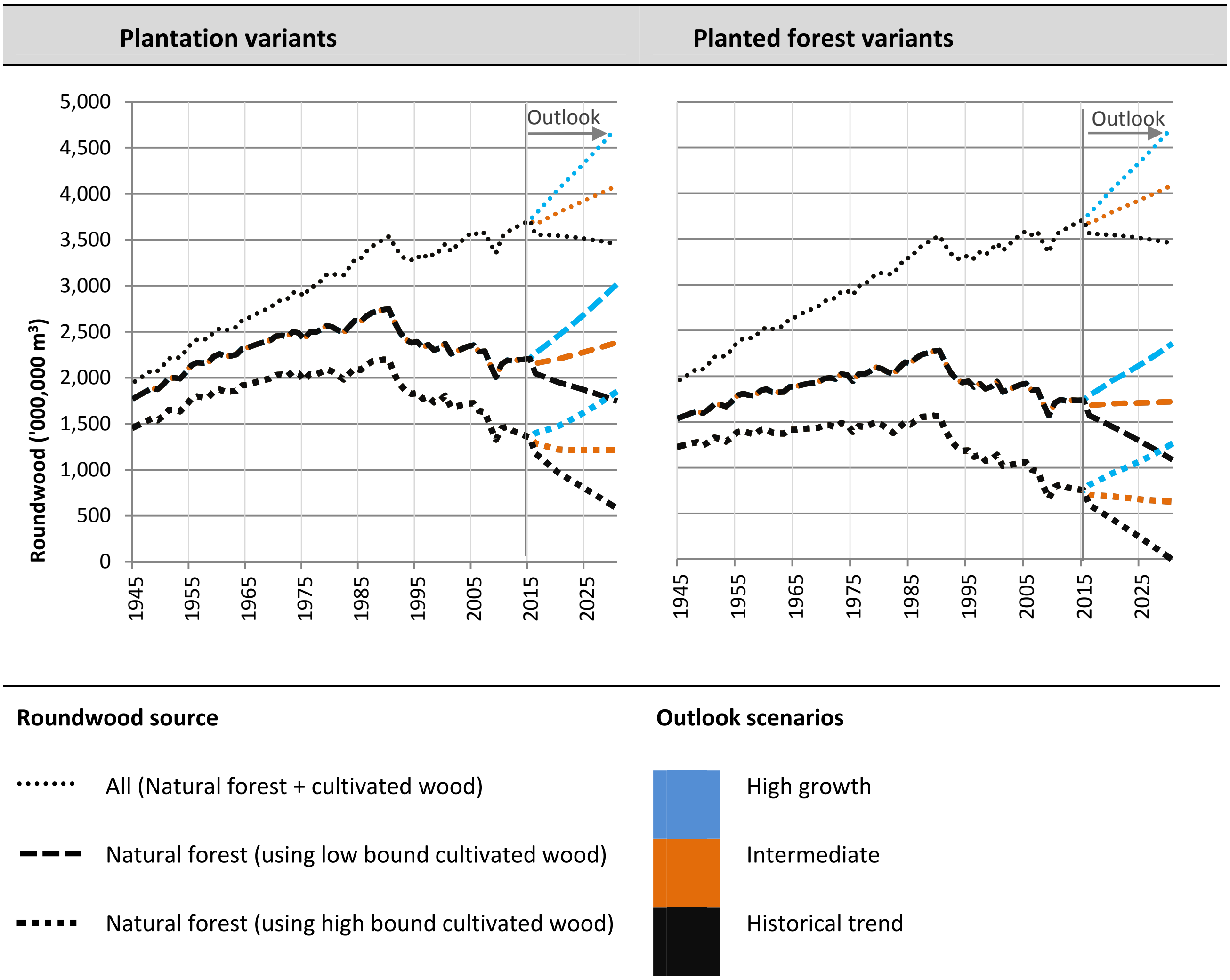

Figure 14. Estimates of global natural forest roundwood production 1945-2030

5.4 Discussion

These findings indicate that roundwood extraction from the world's natural forests peaked around 1989 and has declined since. This pattern of declining wood extraction from natural forests will most likely continue into the future. It would require both sustained high growth in total world roundwood output and lower bound cultivated roundwood supply projections to be operating for the pattern of declining wood extraction from natural forests to change. This would be contrary to the trends of recent decades of negligible growth in world roundwood output and significant growth in cultivated wood estate and outputs, and is considered unlikely.

While the Hubbert curve was developed for non-renewable resources (specifically oil) it can also be shown to represent any resource that is extracted faster than the resource is replenished (Bardi and Yaxley 2005). This analysis finds that total roundwood production has not declined, but levelled, and is consistent with expectations for renewable resources (Hubbert 1993). Nonetheless, this total includes roundwood from both cultivated wood and natural forests. This hides the pattern of roundwood extraction from natural forests, which, when separated out, does appear to have been extracted in a manner consistent with the theoretical pattern of non-renewable resources, or renewable resources extracted at rates above their replenishment level.

It is likely that a combination of factors, shifting both demand and supply, is creating a pattern of production from natural forests consistent with non-renewable or unsustainably extracted natural resources. In summary, these factors include;

- declining natural forest extent (FAO 2010a; Gibbs et al. 2010),

- unsustainable harvesting (Bowles et al. 1998; Shearman, Bryan, and Laurance 2012),
- increasing marginal costs of extracting natural wood (Sohngen, Mendelsohn, and Sedjo 1999),
- decreasing wood volumes from subsequent harvests in tropical natural forests (Putz et al. 2012),
- increasing supply and competitiveness of cultivated trees (Sedjo 2001) driven by both market demands and government policies (Enters and Durst 2004),
- price feedbacks pushing wood-saving technologies and plantation investment (Hyde, Amacher, and Magrath 1996),
- pressure to restrict natural forest harvest through more constrained (and less profitable) forest practices (Pearce, Putz, and Vanclay 2003; Rice, Gullison, and Reid 1997), and,
- increased levels of forest reservation (FAO 2010a), and bans on natural forest logging (as implemented in New Zealand, Thailand and Vietnam, for example).

As noted in the introduction, this transition to cultivated trees as a wood source could allow other natural forest values (especially biodiversity conservation and other ecosystem services) to be better managed while reducing conflict over natural forest resource allocation between wood production and other forest values (Ajani 2011b; Carle, Vuorinen, and Del Lungo 2002; FAO 2010a; Paquette and Messier 2009; Sedjo and Botkin 1997). Understanding the relative influence of the factors forcing the transition, noted above, is important to being able to quantify the extent to which there are forest conservation gains made, or to be made[29]. Reduced roundwood demand from natural forests can also provide opportunities for improvements in conservation and ecosystem service by providing space for previously logged natural forests to regenerate (Berry et al. 2010; Gibson et al. 2011). It can allow additional, precautionary prescriptions to be applied to wood extraction from remaining natural forests (Lindenmayer and Laurance 2012), and the application of methods such as retention forestry and ecological forestry to improve non-timber value outcomes (Clark et al. 2009; Franklin, Mitchell, and Palik 2007; Gustafsson et al. 2012; Lindenmayer, Franklin, and Fischer 2006; Putz et al. 2012). However, these latter 'light footprint' options can add to production costs, further reducing profitability and/or volumes of natural forest roundwood harvest. This could, in turn, have the effect of compounding the comparative cost advantages of cultivated wood sources, thus furthering the transition. Either way, whether more forest conservation, or less wood extraction, wood from natural forests is likely to 'increasingly be a by-product of sustainable management for forest conservation' (Leslie 2005, p.14).

As well as presenting conservation opportunities, the transition of wood production to cultivated trees also has risks to conservation outcomes. The process of cultivated wood establishment has significant biodiversity and ecosystem service implications. In particular, where plantation establishment involves conversion of natural forests, either directly as part of a process of forest degradation, or through forcing food production to displace natural forests elsewhere (for example, Bremer and Farley 2010; Brockerhoff et al. 2008; Gibbs et al. 2010; Pawson et al. 2013), there are high biodiversity and ecosystem service

[29] For example, if growth in plantation wood supply caused by government policy leads to a reduction of demand for natural forest logging then there are potential conservation gains. Conversely logging bans or new forest reserves created over forests for which there is no commercially accessible wood might achieve little real conservation benefit.

costs. This conversion is counter to the potential of cultivated trees to take pressure off natural forests as well as the potential ecosystem services gains to be had through planted forest afforestation (Bauhus, van der Meer, and Kanninen 2010). At a national and regional level there are some data on plantation establishment through conversion of natural forests, for example, in Indonesia (Cossalter and Pye-Smith 2003; Kartodihardjo and Supriono 2000), China (Zhai et al. 2012) and New Zealand (Hartley 2002). However net global data is lacking. In its 2000 Global Forest Resource Assessment, the FAO found that between 1990 and 2000 the global plantation estate grew by 3.1 million hectares a year. Of this, it estimated 1.5 million hectares were the result of plantings on converted natural forests, with the balance through afforestation on other land use classes (FAO 2001, p.9)[30]. The 2010 Global Forest Resource Assessment (FAO 2010a) did not repeat this estimate, although it reported that the rate of afforestation had increased in the ten year period from 2000 to 2010 while deforestation had slowed, indicating a possible decline in rates of conversion.

The above analysis clearly shows a global trend for natural forest wood extraction of increasing production, a peak (around 1989) and subsequent decline in production. This is reflective of the pattern shown in many individual countries, and represents a non-sustainable resource use pattern. The sustainability of global wood production is achieved by an increasing reliance on cultivated wood sources. The data presented here indicate a declining role for natural forests in providing global wood demand. This in turn presents opportunities to reconsider how extensive natural forest ecosystems are

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[30] Plantations in the 2000 Global Forest Resource Assessment are a subset of the planted forest category. They represent only about a half of the extent of planted forests (Carle and Holmgren 2008).

managed, which is particularly important given rising societal demand for non-wood values from these forests.

6 A natural turn: land use change, leakage and forest conservation[31]

> *In some one of its numerous forms, the problem of the unanticipated consequences of purposive action has been treated by virtually every substantial contributor to the long history of social thought.* (Merton 1936, p. 894)

Changes in wood production, forest use and forest extent are often studied within the natural sciences. There is a compelling logic to consider these phenomena as grounded in the realm of the natural. The growth of trees and forests, their location in landscapes, relations with climate and soils, and enmeshment within ecologies lend themselves to dissection by the natural sciences. Likewise, classic economic thought brings the same reductionist spirit to the study of wood/forest socio-ecological systems. The hard to measure power and word plays of human actors can be dealt with by assuming that they are all rational beings seeking to optimise their own well-being.

This is the epistemological basis of the following chapter. While the chapter considers the implications of policy, it does so through the measurement of areas of forest and land tenure, and volumes of wood production and trade. It looks at how these measurements might illuminate key policy considerations in relation to the transition—in particular the ability of industrial plantation policy and forest conservation policy to interact.

[31] From the start of 6.1 this chapter largely follows the text (and figures) from the published paper 'Forest conservation, wood production intensification and leakage; An Australian case', published in *Land Use Policy* (Warman and Nelson 2016). Copyright for this section rests with the publisher, Elsevier.

6.1 Introduction

It is intuitively compelling to design policies that seek to conserve forest ecosystems by creating areas of natural forest that are reserved or protected from wood production in order to maintain or increase their non-wood values[32]. Still, wood harvesting is a mobile economic activity, and attempts to conserve forests through restrictions on production in one area can have the effect of shifting that activity elsewhere. This can negate the conservation benefits of forest protection, potentially offsetting the conservation achieved by the original restriction on production. This phenomenon of inadvertently shifting impacts elsewhere is a policy problem referred to variously as 'leakage', 'slippage' or 'displacement'. Understanding and managing leakage is critical to the success of policy designed to conserve natural forest[33].

The area of the world's forests legally conserved for non-wood ecosystem services is increasing. Globally, the area of forests in protected areas grew from 441 million hectares in 1990 to 651 million hectares in 2015 (FAO 2015b). In Australia the reported area of natural forest in formal conservation reserves grew from 17.6 million hectares in 1997 (National Forest Inventory 1998) to 21.5

[32] This chapter uses the term *forest conservation* to capture the maintenance of forests in a condition that supports their capacity to maintain and enhance the delivery of non-wood values. These include biodiversity and other ecosystem services such as water supply, climate mitigation, carbon storage and cultural values, that can potentially benefit from an absence or reduction in wood production activity.

[33] The Australian literature refers to 'native forests', which has the same meaning as the more widely used international term 'natural forest'. The latter is used here. While there is a spectrum of forest conditions between natural and plantation recognised at an international level (for example, Carle and Holmgren 2003), Australian forests fall nearer to the two ends of the spectrum with clear distinctions between natural forest and plantations. In Australia natural forests are those of indigenous species that have been established through natural regeneration or regeneration methods intended to mimic natural regeneration processes. Plantations in Australia are generally intensively managed monocultures of purpose-selected tree species (and can be either indigenous or exotic).

million hectares in 2013 (National Forest Inventory 2013). The net area of public natural forest allocated for wood production in Australia declined by 45 per cent over the period 1996-97 to 2011-12 from 10 to 5. 5 million hectares (National Forest Inventory 2013, p. 125).

Wood production from Australia's natural forest declined 56 per cent, from 9.6 million m^3 in 1996-97 to just under 4.2 million m^3 in 2013-14. Over the same period wood production from plantations doubled, from 10.5 million m^3 to 21.1 million m^3, due to policies implemented to increase the area of plantation in Australia. There were two phases of plantation expansion; a federal loan scheme to state governments for the development of softwood plantations from 1965 until the end of the 1980s, which was followed by the National Forest Policy of 1995 which included a vision for a threefold increase in plantation area by 2020. The 1995 policy was supported by a favourable federal government tax treatment, Managed Investment Schemes (MIS), which supported the establishment of mainly hardwood plantations (Ferguson 2014).

These policy drivers are consistent with the pattern of change in global trends of wood production to more intensive planted sources (for example, Jürgensen, Kollert, and Lebedys 2014; Warman 2014). This shift is driven by factors already noted such as ongoing improvements in wood use efficiency limiting growth in demand for raw wood (Ajani 2011a; Meil et al. 2007), improvements in tree growing productivity in plantations, as well as declining wood production from natural forest (Shearman, Bryan, and Laurance 2012; White et al. 2006), and increasing pressure for extensive natural forest to deliver non-wood ecosystem services (Millennium Ecosystem Assessment 2005).

The 1995 revision of Australia's National Forest Policy Statement led to the implementation of a series of regionally-based forest policy initiatives known as Regional Forest Agreements (Dargavel 1998; Kirkpatrick 1998; Lane 1999). While the Regional Forest Agreements were focused on a relatively small area of Australia located in south-east and south-west Australia (Clancy and Howell 2013, p. 5), they covered almost all of Australia's commercial natural forest wood-producing regions. The overarching policy objective of the Regional Forest Agreements was to resolve conflict surrounding the use of natural forest that had been intensifying since the 1970s (Clancy and Howell 2013; Lane 1999). The Regional Forest Agreements sought to optimally allocate public natural forest to conservation or wood production. A clear outcome of the policy was an increase in the area of public natural forest allocated to conservation reserves based on a technocratic analysis of their economic, social and environmental value.

It has been asked subsequently if the direct gains in conservation have been offset by displacing wood production to other forests in Australia or around the world (Institute of Foresters of Australia 2011; Whittle, Hug, and Burns 2012). The risk of leakage is a globally recognised phenomenon (Lambin and Meyfroidt 2011; Pfaff and Walker 2010), and has been used to caution against unilateral conservation action by governments (Gan and McCarl 2007). This work seeks empirical evidence for these concerns. Australia's Regional Forest Agreements provide an ideal opportunity to analyse the phenomenon of leakage, and to examine the conditions under which public policy decisions to conserve natural forest are likely to be effective.

This chapter will analyse trends in wood production and trade to assess whether leakage in wood production associated with past policy decisions to conserve areas of public natural forest in Australia has occurred. It systematically reviews changes in wood production sources related to Australia's wood markets and forests. It starts with an assessment of changes in land use related to the policy changes that are reviewed and their impacts on sustainable yield and actual harvest. It then reviews patterns of consumption in Australia before evaluating changes in each of the three main sources of natural forest to which log harvest might have leaked as a result of Regional Forest Agreement land tenure changes.

6.1.1 Past assessments

While leakage is well appreciated as an issue of concern in the literature on forest policy there have been few attempts to estimate leakage arising from policy decisions to conserve natural forest. Two related approaches have emerged—economic modelling of future scenarios and analyses of production and trade data.

Murray, McCarl, and Lee (2004) used econometric analysis to estimate the effects of leakage between two regions when an area of forest in one is conserved—assuming that both are of equal conservation value. When the wood from both forests are perfect substitutes, increased conservation in one region increases the price of wood in both regions leading to reduced consumption, and increased production in the region without forest conservation—that is, you would expect some, but not all, of the wood production to leak. In this model the more imperfect wood in both regions are as substitutes, the more muted is the leakage effect (Murray, McCarl, and Lee 2004, p. 115). In another analysis Sohngen and Brown (2004, p. 837) use an innovative method taking a single country as a supplier to the global market (Bolivia in this case) and find 'that leakage could range from as low as 5% to as high as 39% within the 30-year period of the original project.'

Gan and McCarl (2007) used a computable general equilibrium model to quantify leakage from forest conservation between countries. They determined that forest conservation efforts in Australia and New Zealand (treated as a single region) would have a leakage rate of 89 per cent to the rest of the world, with 70 per cent to tropical forests in developing countries. Leakage levels for the rest of the world ranged from 42 per cent for Canada to 95 per cent for Russia. They found negligible leakage into markets for non-wood alternatives such as other fibre sources, metals and plastics. They also found that coordinated efforts between countries to conserve forests have potential to reduce leakage. A key limitation in this analysis was that it did not distinguish between plantation and natural forest wood sources. As part of work assessing changes resulting from harvest restrictions in the north west US Wear and Murray (2004, p. 328) suggested leakage of log harvest to other regions could have been in the order of 84 per cent.

Smaller estimates of leakage in the literature include that of Murray, McCarl, and Lee (2004, p. 122), who reported that leakage of carbon from forest conservation projects could be 'somewhat larger than the energy sector estimates (previously cited as roughly 5% to 20%)'. Sohngen, Mendelsohn, and Sedjo (1999) estimated that conserving 5 per cent or 10 per cent of North American and European forests would result in leakage of about 1 ha of additional inaccessible land worldwide for every 20 ha set aside—a leakage rate of about 5 per cent.

The analyses above are based on shifts in demand and supply resulting in substitution in the source of wood production which has then been equated to leakage of conservation values. This provides a modelling framework for predicting future leakage only in cases where it can be assumed that production levels reflect conservation values. Leakage effects can also be assessed retrospectively using a stock and flow approach such as that of Meyfroidt, Rudel, and Lambin (2010). They looked at the displacement of land use resulting from reforestation in twelve countries. They found that reforestation had a net positive effect on global forest stocks despite significant leakage through displaced forestry and agriculture, with significant variability between countries.

Whittle, Hug, and Burns (2012) reviewed potential carbon leakage from avoided wood production in Australian natural forest resulting from climate policy, using 'a qualitative analysis of the demand and supply factors' (Whittle, Hug, and Burns 2012, p. 6). They reasoned that reduced log production in one Australian state was unlikely to result in increased wood production from similar forests in other states because of carefully regulated sustainable yield policies. They concluded that substitution towards plantation-grown wood was likely to be limited by the lower structural quality of the latter, although noting the potential for engineered wood products to overcome this. They also concluded that leakage to local privately-owned natural forest and international markets was likely.

With the exception of Whittle, Hug, and Burns (2012) few of these studies take into account rapid development of wood engineering technologies that enable greater substitution between natural and plantation-grown wood. Excluding these productivity trends risks greatly over-estimating the likelihood of leakage. The analysis provided below is *ex post*, relying on observed data which automatically includes recent trends in technical efficiency that affect product substitution and leakage. The significant limitations and varied results in what has been a small and incomplete body of model-based analyses suggest there is value in conducting a robust empirical case study analysis.

6.2 Methods

This section analyses wood production to provide a *prima facie* assessment of leakage resulting from the conservation of public natural forest. Policy decisions to conserve natural forest can be undertaken to meet multiple objectives such as conserving biodiversity, storing carbon, improving water quality and providing recreation areas. Attributing leakage to these multiple interacting values is difficult. This assessment will focus on direct leakage of the targeted activity—log removals—and potential shifts in log removals from newly conserved areas of natural forest to natural forest in other locations or jurisdictions. Log removals are therefore used as a causal indicator of impact on natural forest conservation values.

Data on wood production was available for 1996-97 to 2013-14, a period that corresponds to the implementation of the Regional Forest Agreements and their progressive reallocation of natural forest from production to conservation. Data is reported in financial years—from 1st July to 30th June—consistent with the reporting years used by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), the main source of data for this analysis. Detailed data including supplementary data for graphs shown in this chapter are included in Appendix F.

Changes in the area of public natural forest available for wood production were obtained from *Australia's State of the Forests Reports*, where the net area of forest available for wood production was estimated from the area of production forest minus areas set aside from wood production by informal reserves and other administrative restrictions (National Forest Inventory 2013). Estimates of sustainable yield indicate the amount of wood that can be produced on an ongoing basis. Sustainable yield at the beginning of the Regional Forest Agreement period provides an estimate of the volume of wood that could have been harvested from public natural forest without a change in land tenure. Prior to the Regional Forest Agreement policy, natural forest roundwood extraction had been stable for at least twenty years (Love 1999).

Australian wood production and use data is disaggregated between hardwood (or broadleaved) and softwood (or coniferous). Hardwood is also disaggregated by source, from plantations or natural forests. Softwood in Australia is primarily from plantations of exotic pine (*Pinus sp.*) species, with some limited production from indigenous hoop (*Auracaria* sp.) and cypress (*Callitris* sp.) pine. Cypress log production (c. 2.9 per cent of total natural forest log production) was added to sawlog production from natural hardwood forests, and subtracted from softwood production in the two states where it is produced (New South Wales and Queensland). Data for production, consumption, imports and exports for wood from natural forest and plantations were obtained from ABARES publications (ABARES 2015a, 2015b, 2015c) and supplemented by additional data and disaggregations supplied directly from ABARES (from herein all data provided from these four ABARES sources will be cited as *ABARES data*). Production of plantation logs was calculated by summing production from hardwood and softwood plantations.

ABARES does not include volume information for secondary wood products (wooden furniture, printed paper products [such as books and magazines], paper manufactures and prefabricated buildings) but value ($) data gave some indication of trends. Over the period of this assessment combined net trade in printed paper products and paper manufactures stayed relatively consistent in constant dollar terms, while net trade of prefabricated wooden buildings was negligible in most years except a for a spike in 2011-12 and 2012-13. Wooden furniture net imports however grew significantly across this period, representing a potential source of leakage. For this category, data to calculate the volume of wood imported as furniture was obtained from the United Nations Comtrade database (United Nations 2014), using conversion factors for furniture to whole logs from Contreras-Hermosilla, Doornbosch, and Lodge (2007) and reverse extrapolation to calculate volumes for the first four years of the period for which volume data for wooden furniture were unavailable.

This analysis focuses on the two main log types derived from Australian natural forest—sawlogs and pulplogs. Sawlogs are used to produce sawn timber and veneers (for plywood), while pulplogs are used mainly to produce reconstituted wood panels (mostly medium density fibreboard and particleboard) and diverse paper products.

In order to assess leakage it was necessary to make comparisons between what happened and a counterfactual scenario—what would have happened without the increase in the area of public natural forest allocated to conservation. The assumed counterfactual is as follows. It is expected that the potential log production would have remained constant from public natural forests based on sustainable yield at the time and ongoing government commitment to these sustainable yields. This assumption is supported by already noted evidence of stable production in previous decades. Therefore it is assumed that sustainable yield from public natural forest in Australia would have remained at 2.96 million m^3 for sawlogs, and 3.56 million m^3 for pulplogs[34]. The maximum theoretical wood volume that could be leaked to other sources is the difference between sustainable yield at the beginning and end of the period—1.28 million m^3 of sawlog, 1.56 million m^3 of pulplog and 2.84 million m^3 of logs in total. It is assumed wood production from plantations in a counterfactual would have increased at the same rate observed in the actual. It is assumed that all other trends in demand for wood product would have continued as per the actual in the absence of the Regional Forest Agreement suite of policies. It is assumed that technological improvements would have been the same in both the actual and

[34] Pulp logs are treated as a residual or arising from sawlog harvest in Australia and generally have not had sustainable yields calculated (National Forest Inventory 2013). The estimate here is based on the average ratio of pulp logs to sawlogs from public natural forest for 1996-97 to 1998-99, which was 45/55.

the counterfactual. It is also assumed that the Regional Forest Agreement policy changes had no influence on international sawlog or pulplog production or demand[35].

6.3 Results and Analysis

The sustainable yield and the production of sawlogs from public natural forest in Australia declined by about 43 per cent over the Regional Forest Agreement period (National Forest Inventory 2013) (Figure 15), which is in line with the decrease in area of public natural forest available for production (45 per cent). A critical first observation is that production of sawlogs has been consistently below the sustainable yield (an average of 87.1 per cent of sustainable yield throughout the Regional Forest Agreement period). This tends to indicate that the decline in public natural forest sawlog production was not caused by decreased supply resulting from the Regional Forest Agreement policy but rather from a reduction in demand for natural forest sawlog. This in itself suggests there was no unmet demand from public natural forests as a result of the Regional Forest Agreement policy of increased land protection. Rather, this indicates the land area available for harvest has simply reduced in line with decreasing demand resulting from plantation wood production increases. While other factors might have caused production to be so consistently below sustainable yield, government policy settings throughout this period remained set to maximise sustainable production. This would support a conclusion that there was no unmet demand to leak as a result of the policy change. Despite this, detailed assessment has been undertaken to consider other possibilities that

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35 The relative supply impact, a reduction of 2.78 million m^3 of logs in sustainable yield by 2013-14, represents 0.15 per cent of total global industrial roundwood production of 1,818.2 million m^3 in 2014 and so is not considered likely to have affected global prices.

might indicate negative leakage (including smaller or temporary indications of leakage).

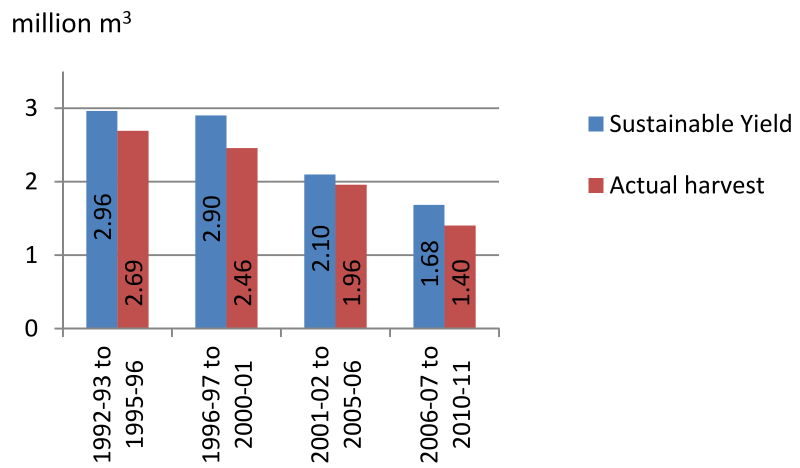

Figure 15. Sustainable versus actual yield of sawlogs from Australia's public natural forest (ABARES data;National Forest Inventory 2013).

ABARES produces estimates of whole log equivalents of consumption for sawlogs (based on sawnwood and veneer consumption) and pulplogs (based on wood panel and paper product consumption) (Figure 16). Australian consumption of sawlog equivalents increased by 27 per cent between 1996-97 and 2003-04, but had decreased by a similar proportion by 2012/13. Sawlog consumption in Australia is correlated to housing starts (Burke and Townsend 2011), and the correlation can be seen in Figure 16. Pulplog consumption has trended slightly upwards over the period at a rate similar to per capita income. This is consistent with global patterns of paper consumption in developed economies (Andres, Zentner, and Zentner 2014). Australian per capita consumption of whole log equivalents of wood products continued to decline through the period[36]. This is consistent with long term trends in wood consumption including changes in paper consumption, recycling and wood use efficiency noted already. Overall, Australian wood consumption does not display any significant change beyond pre-existing trends.

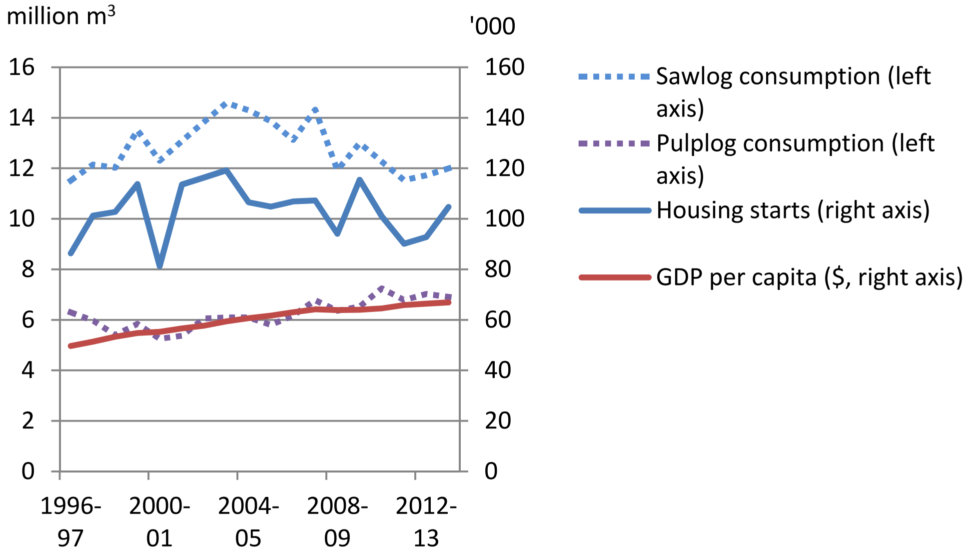

Figure 16. Sawlog and pulplog consumption (ABARES data), housing starts (Australian Bureau of Statistics 2014b) and per capita GDP (Gross Domestic Product) (Australian Bureau of Statistics 2014a).

6.3.1 Leakage to private land natural forest

All states in Australia where natural forest is used for wood production also have similar forest types on privately owned land[37]. These are potential sources of leakage. However, sawlog and pulplog production from natural forest on

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[36] Annual per capita wood consumption in Australia dropped from 1.03 m^3 in 1996-97 to 0.8 m^3 in 2013-14 (an average annual decrease of 0.012 m^3 a year). Previously it declined from 1.27 m^3 in 1966-67 to 1.02 m^3 in 1996-96 (average annual decrease of 0.009m^3 a year).

[37] Nationally, the area of private land natural forest considered suitable for wood production is much larger than that of public natural forest available for wood production (approximately three times), however the forests on private land are generally of poorer yielding forest types and factors such as owner intentions and access to markets limit the ability of private natural forest to supply logs—see Criterion 1 and 2 for further details in National Forest Inventory (2013).

privately-owned land in Australia has followed similar trends to production from public natural forest (Figure 17), contrary to obvious opposite trends which would indicate leakage. Overall, the proportion of Australian natural forest log production from public natural forest increased from 73 per cent in 1996-97 to 86 per cent in 2013-14 (ABARES data). Falling production from privately owned natural forest over an extended period when conservation of public natural forest has increased provides prima facie evidence against direct leakage from public to private natural forest. State by state analysis of private land sawlog harvest was provided in the National Forest Inventory (2013)[38] with average levels of harvest for each of the first three five year blocks of the period under review here (1996-97 to 2000-01, 2001-02 to 2005-06 and 2006-07 to 2010-11). All states except Western Australia saw a decline between the first and last period. The increase in Western Australia represents a theoretical leakage of 1.8 per cent of national natural forest sawlogs[39]. New South Wales and Western Australia both had increases in the middle period. This also represents possible temporary leakage.

It is also possible that if overall demand for natural forest sawlogs declined over the period due to plantation substitution then the rate of reduction in supply from private natural forest might have been faster in the counterfactual and therefore still involves leakage. Nonetheless, as noted above, the rate of sawlog supply from public natural forest has been consistently below sustainable yield at an aggregate national level, making it unlikely that there was any unmet demand from reduced sustainable yield to be leaked.

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38 See Figure 2.20 on page 142 National Forest Inventory (2013) and Appendix F for figures behind the graph.

39 Average harvest of 12,700 m^3 in 1996-97 and 35,500 m^3 in 2006-07 to 2010-11. This increase of 22,800 m^3 represents potential leakage of 1.8 per cent of the national natural forest sawlog production over the period.

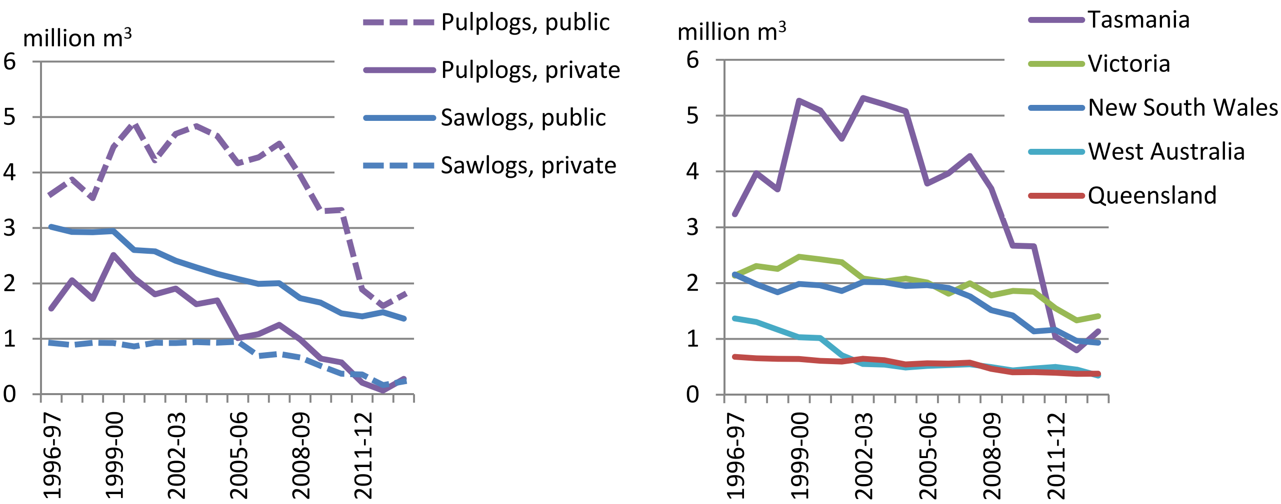

Figure 17. Left—Sawlog and pulplog production from natural forest on public and private land in Australia 1996-97 to 2013-14 [40]*. Right—Log production from natural forest for the main producing states of Australia (ABARES data).*

6.3.2 Leakage between states

Log production from natural forest declined in all Australian states over the period 1996-97 to 2013-14; between 75 per cent in Western Australia, and 34 per cent in Victoria (Figure 17). Production in Tasmania was unique in that it increased significantly early in the period, mostly due to an increase in pulplog production (Figure 18) and is evidence of possible leakage from the conservation of public natural forest in other Australian states. Even so, the scale of this 'bubble' of production was much larger than the maximum potential leakage from other states at the time, indicating drivers other than the change in area of public natural forest available for harvest in other states. In particular, this increased pulplog production in Tasmania coincided with a period of increased conversion of natural forest to plantations (Forest Practices Authority 2014) and

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40 At the time of writing ABARES was not able to provide private land data for 2012-13 and 2013-14. These were derived from the public forest management agency reports for the five states with significant natural forest wood harvests. Details of method are shown in Appendix F.

some growth in demand for natural forest hardwood chips by Japan before a collapse marked by both a decline in overall Japanese hardwood woodchip demand and a shift in preference to plantation woodchip (Macintosh 2013).

Natural forest sawlog production in all states fell over the period 1996-97 to 2013-14, indicating no net displacement of production between states (Figure 18). During the same period production of plantation sawlogs grew considerably (Figure 18), mostly from softwood plantations. As a share of total sawlog consumption, hardwood sawlogs (almost entirely natural forest) fell from 37 per cent to 17 per cent, while softwood sawlogs (almost entirely plantation) increased from 63 per cent to 83 per cent.

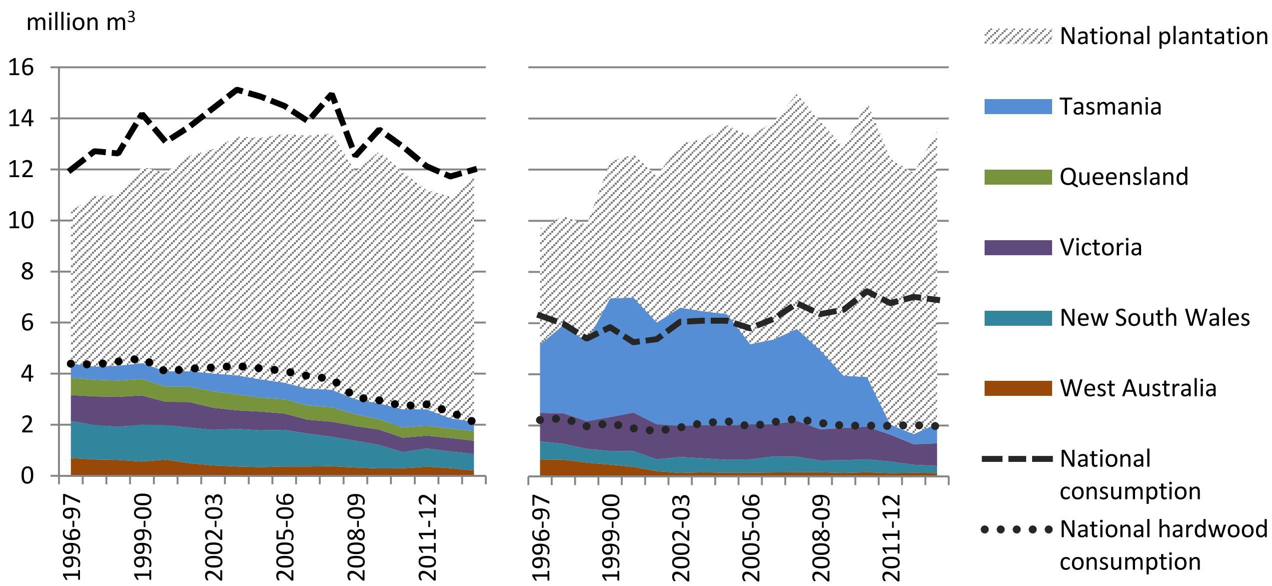

Figure 18. Sawlog and pulplog production from natural forest in each Australian state; total production from plantations; total national consumption of sawlogs; and national hardwood sawlog consumption (ABARES data).

6.3.3 International leakage

During the period of interest, Australia was a net importer of sawlog equivalents and net exporter of pulplog equivalents (Figure 19). Net imports of sawlog equivalents fell by 1.42 million m^3 between 1996-97 and 2013-14 and net imports of hardwood sawlog equivalents fell by 0.18 million m^3 in the same period. This corresponded with a period of significant substitution towards plantation grown sawlogs (Figure 18). Pulplog production from Australia's public natural forest fell from just over 3.61 to 1.79 million m^3 over the period 1996-7 to 2012-13. Over the same period, net exports of pulplog equivalents increased from 3.41 to 6.58 million m^3 (Figure 19). Neither sawlog nor pulplog net trade patterns indicate negative leakage to international forests. Indeed, increased export of plantation pulplogs and decreased imports of sawlogs to Australia may have reduced demand for logs from natural forest in other countries, resulting in net positive leakage (of course this would be attributed to Australian plantation establishment policies rather than Regional Forest Agreement conservation policy).

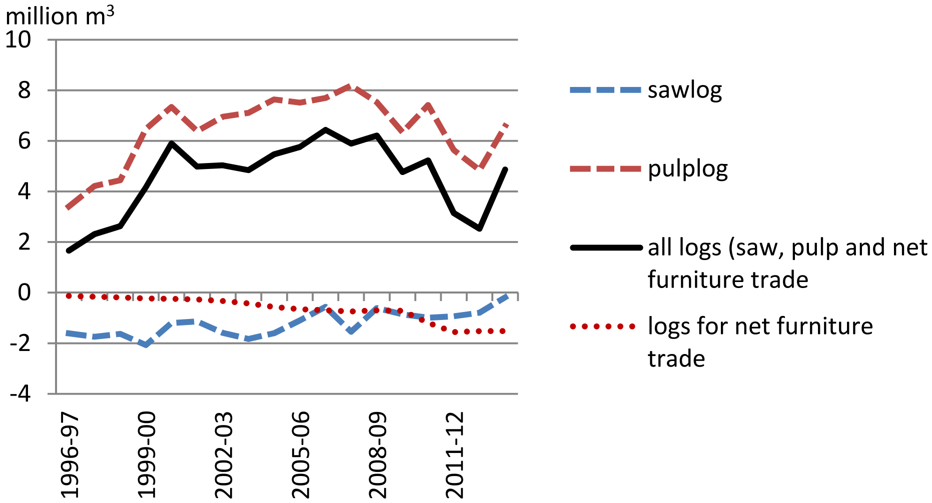

Figure 19. Australian net trade of sawlog, pulplog and combined log equivalents including furniture (ABARES data; Contreras-Hermosilla, Doornbosch, and Lodge 2007; United Nations 2014).

The increase in imports of wooden furniture, a secondary wood product, over the Regional Forest Agreement period represents a potential source of leakage. Whole log equivalents for net furniture trade is shown in Figure 19 and increased from -0.13 million m^3 in 1996-97 to -1.39 million m^3 in 2013-14.

However, this was more than offset by positive growth in net trade for all other log sources. Including wooden furniture trade, Australia's net trade of all log equivalents increased between 1996-97 and 2013-14 by 3.34 million m^3, indicating no net international leakage.

It should also be noted that Australia's furniture production at the start of the period involved only a portion of its wood coming from natural forest with the balance made up of plantation pine, particle board and medium density fibreboard. It was estimated that 5.5 per cent of natural forest sawlogs harvested in Australia in 1998 were used for furniture production (Jaakko Pöyry Consulting 1999)[41]. This would amount to 162,250 m^3 of the sustainable yield of public natural forest sawlog at the start of the Regional Forest Agreement period. Assuming this natural forest sawlog supply for furniture was produced entirely from public natural forest at the start of the period, this gives a maximum hypothetical leakage of 5.8 per cent. However, a number of factors negate this possibility. Firstly, over the Regional Forest Agreement period, whole log equivalents of Australian net exports of hardwood sawnwood increased by 276,362 m^3.[42] That is, increased exports and decreased imports of hardwood sawnwood over the same period more than offset the maximum possible leakage of natural forest hardwood logs for furniture. This is suggestive of shifts towards the manufacturing of furniture abroad (changes independent of the Regional Forest Agreement policy rather than shifts of wood sourcing which would constitute leakage). Further contradicting the possibility of leakage, there is evidence of an increase, not a decrease, in the use of natural forest hardwoods in

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41 In addition Ximenes and Gardner (2005) reported there was 46,700 m^3 a year of natural forest hardwood timbers used in Australian furniture production in 1999 and noted a large switch from hardwoods and in particular jarrah to plantation softwood in the preceding three years.

42 See Appendix F.

Australia in furniture and other high value applications over the period (URS 2007)[43].

6.4 Discussion

The results indicate that there has been no significant leakage of wood production to other natural forest—either locally or internationally—from the conservation of Australia's natural forest under the Regional Forest Agreements. The main reason for this is that substitution towards domestic plantation wood supplies have more than met this demand. It is also possible that, as Australia increased net exports of whole log equivalents, positive leakage from plantation establishment may have occurred as wood from Australian plantations displaced wood that would otherwise have been harvested from natural forest internationally. The overall finding of minimal wood production leakage is at odds with a number of past, mainly model-based or first-principle assessments that have forecast relatively high levels of leakage. The analysis undertaken here suggests that overestimates of leakage can result from underestimates of substitution effects. In the Australian case there is clear evidence that substitution with emerging plantation wood supplies has been critical in negating possible leakage. This points to the importance of distinguishing between natural and planted wood sources when estimating potential leakage of forest conservation impacts.

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[43] For example, the portion of New South Wales public natural forest hardwood sawlog harvest being used for 'Joinery/furniture' grew from 1 per cent in 1995-96 to 7 per cent in 2011-12 (Wackernagel et al. 2004). Given a halving of public natural forest hardwood sawlog harvest in New South Wales over this time (National Forest Inventory 2013) this equates to more than a threefold increase in sawlog production for these purposes. The overall decrease in natural forest hardwood sawlog production occurred through a significant decline in its use for structural purposes.

The Australian case shows shifts in processes along the supply chain have reacted to the reduced supply from natural forest in ways other than simple displacement of wood sourcing to other natural forest. A likely factor to consider in leakage assessment is the extent to which a shift in relative prices leads to improvements in productivity rather than simply displacing the activity of concern (Schwarze, Niles, and Olander 2002). Improvements in log growth in plantations and log use productivity at multiple stages of the supply chain can have a significant impact by increasing plantation log supply and reducing overall wood demand without decreasing the supply of wood product outputs (Ajani 2011a; Hyde, Amacher, and Magrath 1996; Meil et al. 2007). This is reflected in Australia's reducing per capita consumption of wood. To the extent that they reduce demand for logs, improvements in productivity through induced innovation can act as reverse or positive leakage. The analysis here also shows that while plantation wood sources are often not perfect substitutes for natural forest timbers, changes in technology and processor and consumer preferences can facilitate major cross substitution effects over time.

There is limited evidence (in particular due to the presence of other significant drivers) of short term leakage of pulpwood extraction from other Australian states to Tasmania, and stronger evidence of shifts in sawlog production to private natural forest in New South Wales in the middle of the period (that had ceased by the end of the period), and of small (1.8 per cent) leakage to Western Australian private natural forests by the end of the period. The latter would make an interesting case for closer assessment in order to understand the role of the relatively unique properties of the Western Australian eucalypt species such as jarrah. The growth in furniture imports is suggestive of weak leakage patterns identified in carbon research (Peters and Hertwich 2008). Nevertheless, in Australia's case the net whole log equivalent trade balance more than compensated for the increase in wood inflows in furniture. The case for strong leakage in furniture resulting from policy restrictions on public natural forest is, however, contradicted by a number of factors, as described above. Finally, none of the above possible leakage outcomes is supported by evidence that sawlog production from public natural forest has consistently been lower than allowable sustainable yields.

The major volume change in net pulplog exports is supported by a number of previous studies which concluded that a growing international supply of plantation woodchips would lead to a decrease in demand for woodchips from Australia's natural forest (Ajani 2011b; Nelson and Shield 2003; Pollard 2006). The historical data presented here confirms these previous analyses.

The results of this analysis are consistent with findings that some countries can 'exhibit net land sparing gains' (Meyfroidt, Rudel, and Lambin 2010). It supports previous analyses that have suggested wood production from highly productive plantations may compensate for reduced areas of wood production in natural forest (Chomitz 1999; Murray, McCarl, and Lee 2004; Wunder 2008). In Australia's case, land sparing through intensification of wood production from plantations has allowed a significant increase in natural forest conservation with no significant leakage of wood production to other natural forest. Understanding the full potential for land sparing benefits to be realised will also require further analysis of the impacts of creating the plantation estate[44]. The conversion of natural forest to industrial plantation can carry considerably higher conservation costs at the site of conversion than log extraction from natural forest alone

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[44] It is considered that roughly half of the 2 million ha of Australia's plantation estate has been established through conversion of natural forest rather than on previously cleared land, with the bulk of this occurring prior to the introduction of restrictions on conversion in the 1990s (for background see Gerrand et al. 2003; Stephens, Tickle, and Sun 1998).

(Brockerhoff et al. 2008), although, as part of a landscape-wide land sparing approach, it can still produce net conservation benefits (Edwards et al. 2014). Plantation established on already cleared or degraded lands can go some way to further improving the net conservation outcome (Bauhus, van der Meer, and Kanninen 2010), although displacement of agricultural production can also have some conservation costs through increased demand for agricultural land driving deforestation elsewhere (Meyfroidt and Lambin 2009).

The possible short term leakage noted above is consistent with the findings of Meyfroidt and Lambin (2009) that it can take time for intensification effects to replace immediate leakage effects that stem from forest protection policies. It is likely that this delay results not just from the need to establish alternative intensive wood production, but also the time taken for processors and consumers to adjust technologies and demands to utilise the new, often imperfect, substitutes. A critical factor in the Australian experience is that the establishment of the pine plantation estate that effectively substituted for reduced sawlog supply from forest protection policies was put in place some decades before the forest conservation policies of the Regional Forest Agreements.

Substitution towards increasingly low cost and consistent quality plantation wood raises a question of whether and to what extent market forces and plantation establishment policy alone would have delivered the main conservation benefit of new reserves—reduced logging pressure. Faced with this scenario, forest managers choosing the most efficient harvesting method may have turned to more productive areas of forest with high conservation values. Harvesting highly productive areas of natural forest may then have enabled the economic viability of natural forest wood production to compete with plantation production in the short to medium term. In the long term, costs would inevitably rise as harvesting moved into less productive areas of natural forest. The Regional Forest Agreements are therefore likely to have led to a net conservation gain by making areas of natural forest unavailable for wood production and accelerating the pace at which the cost advantage of plantations could be realised. This is similar to the policy logic of putting a price on carbon to avoid the future consequences of climate change.

In popular and political discourse, conservation and industry policy are often assumed to be in tension, if not completely irreconcilable. The Australian experience described here suggests that a significant degree of alignment can arise between conservation policy and industry policies that support plantation development. Policies that have increased the productivity of plantations have enhanced conservation outcomes, in part by making the production of wood from natural forest less competitive. By restricting access to natural forests, conservation policy has reduced the productive potential of natural forest (increasing costs), accelerating substitution towards plantation-grown wood. The complex drivers of policy make it difficult to assess the extent to which this outcome was planned in the Australian case. Nevertheless, the outcome is sufficiently clear to allow a conclusion that plantation development can be a policy enabler of both increased forest conservation and sustained wood production. The key to doing this is to match conservation policy with plantation development via industry policy to ensure an alternative supply of wood with low conservation impacts.

Over recent decades Australia has implemented policies that have transferred public natural forest from wood production to conservation. This chapter considered whether the resulting reductions in wood production led to leakage of wood production to natural forests elsewhere and thereby undermining the conservation outcomes intended. It found that, because of substitution of wood supply from increasing low-cost plantation wood sources, this did not occur. The Australian experience documented here shows that it is possible for governments to take unilateral action and have a net positive effect on both local and international conservation.

7 A social turn: decentralisation in Indonesia—a forestry history[45]

> *Another example from the mid-19th century is the Swiss debate over the great inundations in several Alpine valleys which were presumed to be caused by deforestation in the mountains. As Christian Pfister and other Swiss historians have recently pointed out, the environmental historian should not too eagerly echo these complaints … since it is neither proven nor even probable that the destruction of woods by mountaineers was the real cause of the inundation catastrophes. These accusations should rather be put in the context of power relations: environmental complaints served as a means for the dominant Swiss lowlands to get control over the mountain forest* (Radkau 1996).

A quote about Swiss forestry might seem a strange choice for the start of a chapter on Indonesian forestry. However, it speaks clearly of power and the role of power in developing and spreading stewardship forestry ideals. The analysis that follows can stand as a case study with more universal application. Analysing the social by following the threads of power is the second 'tact' of Latour's tripartition of critique for networks. Our attention now shifts to the social (and the political), where the institutions of the socio-ecological system can be analysed and understood. This case study focuses on the role of institutions of forestry in Indonesia, a country with a complex history at the intersection of many of the key global processes described in this thesis. Emphasis is placed on governance and social and political dimensions of wood/forest socio-ecological systems.

[45] From 7.1 this chapter closely follows the text that appears in the paper, 'Decentralisation and forestry in the Indonesian Archipelago: beyond the *big bang*', published in *South East Asia Research* (Warman 2016). Copyright for this chapter rests with the publisher, Sage.

7.1 Introduction

It was considered opportune to give particular attention to the role of centralisation in governance and forestry. This had been widely written about in the several years after Indonesia's change to decentralised governance following the fall of Soeharto in 1998. However, several years had now passed since that flurry of academic interest. At the larger scale the question of centralising and decentralising governance is of considerable relevance to the unfolding of the greater global transition of wood production where a range of processes have taken place involving shifts of power between centres and peripheries, such as that of the industrial core and its periphery, the dissemination of stewardship forestry from the colonial core, and the rise of the south as a force in global wood production.

As governments and other policy actors grapple with forest governance issues, so, too, the forest use and wood production systems that are governed are evolving. Changing socio-political-economic processes related to the development of industrial societies have created distinctive patterns of forest use in the lead up to, during, and after, rapid industrial development. These patterns include the forest transition which relates to changes in forest extent, and interrelated progressions of wood production and forest use, from natural forest exploitation, through stewardship and managed forestry to cultivated wood methods—mostly plantations. As noted earlier William Hyde describes a three stage process of forest use, with a first stage involving new settlements and forest frontier exploitation converting forest to agricultural land with opportunistic wood use, followed by a second stage where demand for land conversion has ceased being the primary driver but extraction of commercial wood species continues to push it further into the forest frontier (Hyde 2012). This stage often includes selective extraction of high value species only, illegal logging resulting in part from poor property rights allocations, and little or no active forest management beyond the extraction of wood. Hyde observes that East Kalimantan has been an example of these two stages. Similar patterns have occurred in Sumatra and Papua. The third stage is the mature forest frontier, where the cost of further extraction from the forest frontier becomes more than the cost of growing wood in managed forests or other forms of wood cultivation such as plantations and agroforestry on previously cleared land. Hyde notes that the third stage has been reached and is well established in Java.

These three stages can also be described in terms of their institutional expression. The first stage has little in terms of formal institutions, being associated with frontier exploitation. It is a period when expanding populations take advantage of new demand for agricultural land and wood from what is often seen as an expansive commons, and is often conducted with little or no central government control, or modern legal or tenure frameworks. On the other hand, where there are indigenous or long standing local populations there is likely to be a range of customary or traditional practices and tenures. Subsequent stages of forestry evolve in response to increased demand for stronger institutions of control, law and law enforcement. There is an attempt to clarify property rights and establish formal institutions of forest management. This has often involved the assertion of central government control over large areas of forested land, and, thus, the emergence of forestry as a form of leviathan governance, responding to what were seen as unfolding tragedies of the commons[46]. The institutions developed by central governments at this stage are often imposed over pre-existing customary institutions and tenures of ownership. As will be described later, this

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[46] See, for example Galudra and Sirait (2009) for a description of the use of hydrological concerns to justify central control of forests in colonial Java.

stage can be clearly seen in the development and subsequent resilience (resistance to, or robustness, in the face of change) of Indonesia's central institutions of forestry. From this develops the third stage, within which management of forests becomes contested. Institutions competing with those of forestry include non-government organisations, protected area management agencies and revitalised traditional owner interests, especially in the extensive remaining areas of natural forests at and beyond frontiers of wood extraction. At the cleared/developed land interface there is also an increased blurring of forestry and agriculture as wood cultivation becomes established in lands previously cleared of forests. At this point a series of spheres of interest[47] in forest management and ownership have developed that are international, national and local[48]. They have developed in a context that is driven by a struggle for access to and control over political power and resources. Figure 20 provides a schematic overview of the contested spheres of interest paradigm. The following history expands on the nature of the contest between these spheres through a review of the shifts between centralising and decentralising governance.

47 'Sphere of interest' is used in this context to describe a geographic range of interest based on the spatial sphere of activity that will affect actors' interests.

48 Though in the earliest examples of stage two and three (for example, the Middle Ages of Europe and pre-colonial Java) notions of 'international' and 'national' did not exist as they are understood now, the distinctions are used here as they refer to a period of Indonesian history in which they later become significant.

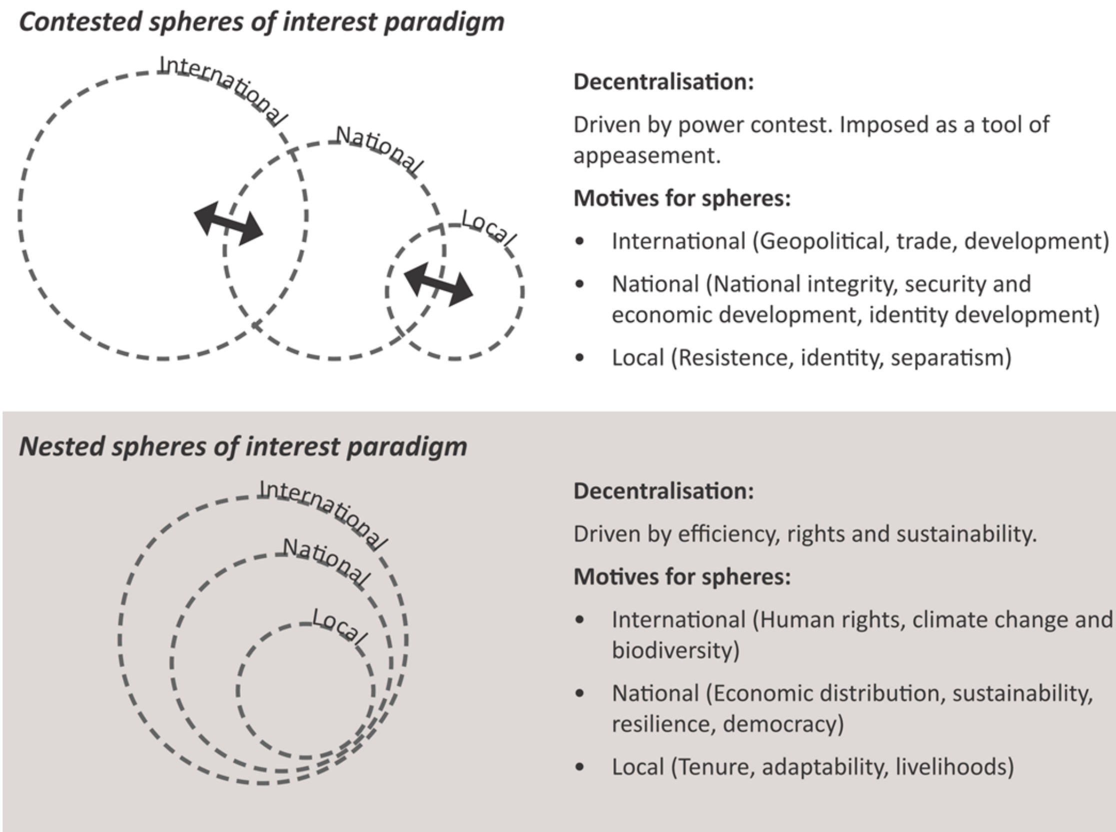

Figure 20. A schematic of the spheres of interest, including drivers, relationships and the motives of individual spheres.

In 1999, immediately after the Asian financial crisis and the end of the presidency of Soeharto, new laws in Indonesia decentralised substantial responsibilities, powers and finance from the central government. It has been cited as one of the most significant decentralisation efforts undertaken in recent times (Crouch 2010). Indonesia has a long history of tension between central interests, generally based in Java, and the other islands of the archipelago. With forestry being a significant part of Indonesia's economy the evolution of forestry institutions has featured strongly in the development of core/periphery relationships. There is a considerable body of literature on the impacts of the decentralisation of government in Indonesia in the *reformasi*[49] period. In particular, the impacts of decentralisation in forestry (Barr et al. 2006b; Larson 2005; Moeliono, Wollenberg, and Limberg 2009; Palmer and Engel 2007), and subsequent recentralisation (Bullinger and Haug 2012; Crouch 2010), have been richly reported.

The use of forests and the growth of forestry have been central to the development of the Indonesian state. Indonesia has one of the most important areas of forest in the world, of significant social, political, ecological and economic value, to both the archipelago, and beyond[50]. Forestry and its institutions have experienced ongoing evolution. Forest management and wood production in Indonesia has undergone significant changes over the last few decades (Obidzinski and Chaudhury 2009). Deforestation rates have been high by world standards and peaked in the years 1997—2000 (Ministry of Forestry 2009). Plantation wood supply, as a portion of total pulplog demand, rose from negligible levels in 1999 to around 20 million m^3 a year ten years later (Obidzinski and Dermawan 2012, see also Figure 21). In the midst of these developments in forestry there has been a widely studied process of change of forestry governance; the *big bang* of decentralisation following the end of the New Order[51].

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49 *Reformasi* is used here to refer to the period of governance reforms undertaken after the end of the Soeharto government in 1998.

50 Indonesia has the eighth largest forest estate, the third largest area of tropical forests and had the second, third and second highest rates of forest loss in the world for 1990-2000, 2001-2010 and 2011-2015 respectively (FAO 2015b). Indonesia is a significant player in global wood products trade. In 2014 Indonesia was ranked 7th in the world for industrial roundwood production, 4th for pulplog and 9th for wood based panel production (FAOSTAT 2013, 2014).

51 The New Order is a term used here to describe the Soeharto government of Indonesia for its full period from 1966 to 1998.

As noted earlier, forestry has played a key role in colonisation and the development of nation states including through assertion of power by central interests over land and people (Bryant 2002). In the case of Indonesia, this led to conditions under the New Order whereby forestry and the management of 143 million hectares of forest were under almost total central government control[52]. This context helps explain the subsequent strong interest in decentralisation for forest policy analysts in the years immediately after the *big bang*. This analysis here however, aims to site the *big bang* in the longer sweep of Indonesia's history and global patterns of forestry, rather than within its immediate historical context. It does this by reviewing the history of forestry in Indonesia and related developments of centralising and decentralising processes in governance. From this viewpoint it will review the effects the *big bang* from further away in time than much of the analysis that occurred during and immediately after the *big bang* and speculates on new potential opportunities for finding effective and lasting decentralisation in forestry governance in Indonesia.

7.2 Background

Decentralised governance is distinct from federal systems (for example, Australia, Malaysia, US) where delineation of powers is clearly spelt out in a Constitution (Gregersen et al. 2005). By contrast, Indonesia is a unitary state where formal powers reside with the centre. Decentralisation refers to the shift of powers and responsibilities from a centralised government to components of its jurisdiction. These powers/responsibilities can be *political* (making decisions), *administrative* (managing allocated resources and responsibilities), *fiscal* (taxation

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[52] 143 million ha was 76 per cent of the total 187 million ha of land in Indonesia. For details on extent of forest and tenure see Ministry of Forestry (2009) note 8, at p 9.

and revenue raising), and *market* (privatisation and deregulation of private industry) (Blaser et al. 2005). In Indonesia these responsibilities can shift from the central government to provincial, district or village levels, as well as through shifts in ownership and rights to customary custodians and private firms (Ferguson and Chardasekharan 2005).

Decentralisation of governance in developing countries was advocated by developed countries and international development agencies in the 1950s and 1960s. This was strongly associated with colonial powers seeking to establish what they considered were the good governance benefits of sharing power with local government jurisdictions; specifically, as modelled on governance structures that existed in developed countries (Conyers 1983). In the late 1970s and 1980s it emerged again as a 'fashionable' topic, especially in international development organisations (Conyers 1983). This time there was a stronger academic basis and it was seen in particular as a vehicle to further rural development in developing countries (Ahmad and Talib 2011).

Despite this longstanding history of advocacy there is still considerable uncertainty about the advantages and disadvantages of decentralisation . Examples of adverse findings include increased deforestation stemming from increasing subdivision of districts (Burgess et al. 2012), decreasing economic equality as a result of poorer regions lacking capacity or resources to take advantage of the opportunities potentially offered by decentralisation (Rodríguez-Pose and Ezcurra 2010), disappointing gaps between goals and actual outcomes, especially when a top down approach has been applied (Wunsch 2013) and mixed outcomes for local communities subjected to changes in centre/local control of resource rents (Bullinger and Haug 2012). An overarching review of decentralisation research in relation to forestry in Indonesia was also mixed in its findings (Barr et al. 2006b).

7.3 History of Indonesian (de)centralising relations in forestry

The colonising Dutch struggled over a number of centuries to assert control over the archipelago (Vlekke 1959). Only in the early twentieth century did they reach a point where they were able to tenuously control most of what is now Indonesia and imagine it as a territorial unit (Ricklefs 2001). During this time there was a concurrent expansion in forestry control, which was entwined with the territorial mission of the colonists (Galudra and Sirait 2009; Peluso 1992; Peluso and Vandergeest 2001).

For the most part, early Dutch forestry interests were focused on the naturalised teak (Pandey and Brown 2000) resources of Java. It was here that the strongest instruments of central state control were progressively instigated. This started in the early nineteenth century and culminated in the Forestry Law of 1927 that gave the colonial Forest Service control over all forests on Java (Peluso 1992)[53]. However, they still struggled to establish control over forests on the Outer Islands (Galudra and Sirait 2009)[54]. At this stage the forests of the Outer Islands were of little forestry-related economic interest, and largely controlled by traditional ownership patterns. Rulings in the colonial judiciary and a spirited debate about the legal rights of the state versus traditional ownership of forests beyond Java (Peluso and Vandergeest 2001) possibly also kept expansionary impulses at bay. This state of affairs set the pattern for forestry in Indonesia at independence—a highly centralised Javan forestry and a high degree of traditional control in the Outer Islands.

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[53] Peluso and Vandergeest (2001) show that in 1929 the Javan Forest Service was well established, with nearly 6,000 staff. This was a level of staffing and staff to forest area ratio much higher than comparable jurisdictions in Southeast Asia at the time.

[54] The Outer Islands refer to the islands of Indonesia outside Java and Madura.

The new Indonesian Forest Service maintained key parts of the personnel, culture and structure of the Dutch colonial Forest Service (Peluso 1992) and there were no changes to the forestry laws or regulations of the Dutch during the period of Japanese occupation or subsequent first decade of independence (Kartasubrata 1985). The inherited residual powers of provincial governments on matters of forestry were clarified in 1957 when Soekarno moved to ease concerns in some provinces that the Jakarta government intended to claim control of the natural resources of the Outer Islands (Barr et al. 2006a). This regulation spelt out that control over issuing concessions resided with the provinces (outside Java and some limited parts of Kalimantan under the control of the national Forest Service). It was an act of decentralisation , particularly of administrative responsibilities. Despite this, it also required those permits and the management decisions of the provincial forest managers to be consistent with the centre's regulations (Kartasubrata 1985).

As before, *adat*—customary or traditional practice and law—legal systems continued to be recognised throughout the Outer Islands. In contrast, on Java the lack of recognition of these, based on the central Forest Service's complete ownership of Java's forests, was a source of considerable tension (Barr et al. 2006a). In 1960 the Basic Agrarian Law aimed to clarify the dual national/*adat* legal system in relation to land ownership and control. It was influenced by the Indonesian Communist Party and intended to extend and preserve rights of the population to the use of the land (Peluso, Afiff, and Rachman 2008). However, like the 1957 forestry regulations, it contained a measure that simultaneously entrenched central government control—a caveat that land was controlled by the central government where it was in the 'national interest'. In any conflict between regional interests or central (national) interest, a critical veto on power sharing remained with the centre.

At this time there was also growing international pressure for the Indonesian Government to promote economic growth through the exploitation of its natural resources (Barr et al. 2006a), including forestry [55]. The Soekarno government took its first steps in this direction establishing some logging concessions on Kalimantan in the 1960s (Barr et al. 2006a). At this stage there was still a reasonable degree of consideration for *adat* in forests in the Outer Islands. It is likely that this reflected a lack of technological means, and commercial potential, to develop the hardwood resources of the natural forests of the Outer Islands. That changed dramatically with the start of the New Order.

A year after Soeharto commenced the New Order, the Forestry Law of 1967 was passed. It established central control over 143 million hectares of forest across Indonesia (Barr et al. 2006a). Subsequent regulations gave the central government the ability to issue large logging concessions over this area, while provinces continued to be able to also issue licences. For this period, called *Banjir Kap*[56], there was a rapid expansion of logging, characterised by much confusion and poorly controlled exploitation. In 1970 Soeharto issued Regulation 20/1970, outlawing *Banjir Kap* and giving the central government sole rights to issue logging concessions, which had to be bigger than 50,000 ha (Ross 2001). The central government did this rapidly. Indonesia went from a country that exported 209,000 m^3 of wood in 1965 to being the world's largest tropical wood exporter in the late 1970s, exporting more than 20 million m^3 of unprocessed logs a year (Barr et al. 2006a). In this period the two main policy solutions to common-pool resource problems were fully implemented—leviathan control

[55] For a discussion of the ideas being promulgated in the 1960s for the use of forests to advance economic development in the non-Western world see Westoby (1987).

[56] 'Cutting during the flood', a method of hand logging after which this period was named. The method utilised rivers to float logs to markets and involved many small scale local operators (Ross 2001).

over forests, in partnership with a privatised system of concessions over the forest estate.

In the early 1980s a total ban on the export of whole logs was instituted to encourage domestic processing (Hyde 2012). This led to consolidation of the nation's wood industry into a much smaller number of larger companies dealing directly with the central government. This served to further consolidate central control over forestry (Barr et al. 2006a). The boom in whole log exports ended but was quickly replaced by a boom in plywood export. Then, in the 1990s, a pulp and paper boom followed (Figure 21). Each of these waves of wood processing—whole logs, plywood, pulp and paper—placed Indonesia as one of the world's largest exporters in each category. Wood and wood products were a major source of export earnings for the country during this time. Each of these subsequent waves also involved a shift to progressively more capital intensive forms of wood processing. More capital intensive wood processing involved greater degrees of foreign investment and ownership, larger corporate players, increased wealth distribution issues within Indonesia, and geopolitical and trade considerations—all areas of responsibility to justify (require) the central control of Jakarta. Further, in the political contest for resource and wealth control, the bigger players and sums of money involved would also have served as incentive for increased central government control.

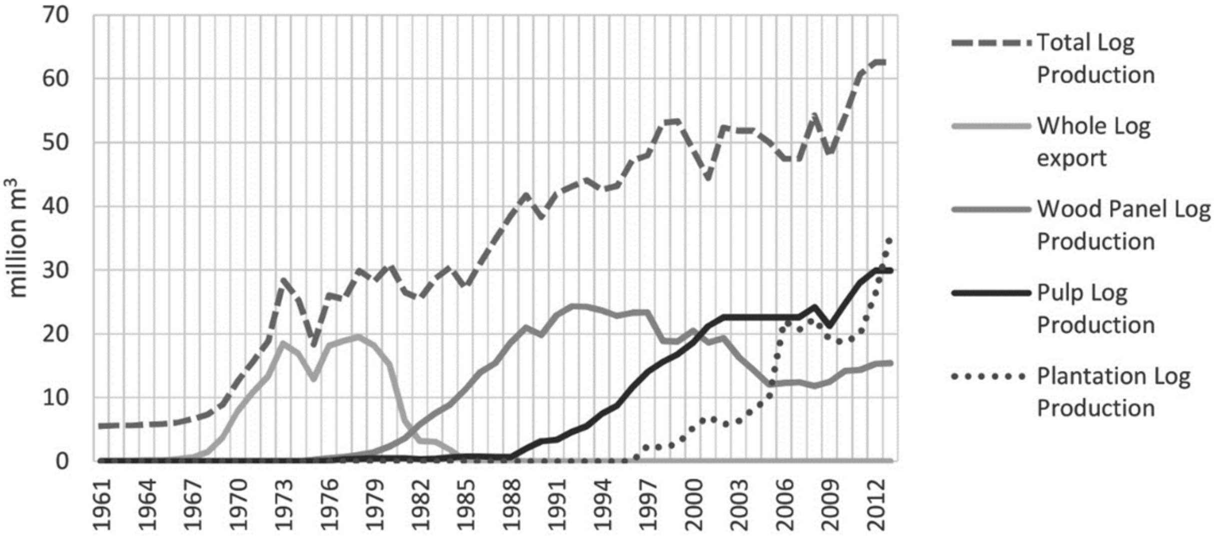

Figure 21. Production of total logs and the three successive waves of log uses[57]

In the late 1980s there was a realisation that the rate of natural forest exploitation was unsustainable. A plantation establishment regime to provide a long term sustainable wood supply was started, wherein wood companies were given access to areas of forest for conversion to plantation (Barr et al. 2006a). This was in response to unbalanced wood industry development policy over previous decades that involved subsidised and uncontrolled expansion of processing capacity, requiring an unsustainable rate of harvest from Indonesia's natural forests. Consequently, the wood products sector went into deep decline in the 2000s, with nearly one third of wood products sector jobs going in the period 2001 to 2006 alone and 2004 to 2006 seeing a 55 per cent decline in plywood export and 40 per cent decline in sawn timber exports (Obidzinski and Chaudhury 2009, p. 80). In addition, permits to convert forest to palm oil were also issued on a large scale in the 1990s (Barr et al. 2006a). Combined with illegal

57 Source: (FAOSTAT 2014). Wood panel logs conversion factor from the Contreras-Hermosilla, Doornbosch, and Lodge (2007) and plantation wood compiled from various Indonesian Ministry of Forestry reports.

logging, these processes contributed to Indonesia having one of the world's highest rates of deforestation through the 1990s. There was a growing recognition of serious deforestation, industrial overcapacity in the wood processing sector and unsustainable logging rates (Barr et al. 2006a).

This forestry crisis was unfolding as the New Order started to collapse, both in the wake of the Asian financial crisis of 1997, and a downturn in support for Soeharto. There was considerable concern that Indonesia was on the verge of becoming a failed state. In response to this crisis, the government of President Habibie, who replaced Soeharto in 1998, moved quickly to decentralise power (Nordholt and Van Klinken 2007). There was a calculation that this was needed to stave of disintegration of the nation in the face of growing separatist agitations, part of which involved demands for greater access to natural resource wealth within the regions (Barr et al. 2006c). Simultaneously, decentralisation allowed a shift of power to the regions, where Golkar's[58] hegemony was sufficiently well established to be thought resilient to the potential loss of power facing the national government through proposed fair elections (Crouch 2010). At the same time as these internal pressures were occurring within Indonesia, international development policy and, specifically, trends in international forest policy were placing greater emphasis on the value of decentralisation as a means to increase 'efficiency, equity and democracy' (Larson 2005, p. 3). International development agencies and forestry organisations promoted decentralisation of financial and governance structures for communities living in forested regions (Blaser et al. 2005). In its negotiations for structural reform after the Asian financial crisis, the International Monetary Fund also added indirect pressure for decentralisation in Indonesia (Barr et al. 2006c). These pressures combined to see

[58] Golkar was the political party of the ruling regime during the New Order.

the implementation of 'one of the developing world's most decentralised systems' (Crouch 2010, pp. 8-9).

The period of decentralisation was one of intense jockeying for influence. New coalitions were formed between local interests seeking regional advantage from the diffusion of power away from the centre (Kimura 2010). Forestry governance was left in a confused state as a result of unclear divisions of responsibility between the centre and the regions. Indeed, Resosudarmo has observed that '[n]owhere has the disorderly and sudden nature of the changes brought about by decentralisation been more apparent than in the management of Indonesia's forestry resources' (Resosudarmo 2003, p. 230). Despite the passing of *Otda*[59] laws (Law No 22) that devolved considerable forestry management from the centre, it was only a few months later that the new Forestry Law[60] of 1999 was adopted. This acted to re-established central control over forests and their use (Siswanto and Wardojo 2005). However, it created an environment in which conflicting laws created considerable legal ambiguity (Arnold 2008) that led to numerous demarcation disputes between various levels of government and private businesses (Crouch 2010).

Regulations passed soon after the 1999 Forestry Law assigned district governments the rights to issue small (<100ha) wood permits. John McCarthy describes the period of confusion between 1999 and 2003 in the province of Kalimantan Tengah (McCarthy 2007). An increased level of lawlessness in wood logging reigned—there was a proliferation of armed pirates and protection gangs on the main rivers—until a procession of central government regulations

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59 *Otda* from *Otonomi Daerah*, meaning Regional Autonomy (see Arnold 2008).

60 The law granted the Ministry of Forestry responsibility for 120 million ha of forest (Irawan, Tacconi, and Ring 2013).

reinstated central control. This chaos is reflective of the period of *Banjir Kap* that followed the Forestry Law of 1967, described earlier. In both cases the response to confused enactment of newly implemented dual governance systems in an environment of radical change was to move power back to the centre. Two examples of this shift from the *Otda* period were a series of central government moves to rein in the proliferation of small scale wood licences being issued by the regions, culminating in regulations in 2002 shifting responsibility back to the centre, and a decree in February 2001 affirming that ministerial orders (central government) overruled regional regulations. By 2002 forestry was undergoing significant recentralisation (Barr et al. 2006d).

Central control was more generally reconsolidated with the passage of Law 32/2004. This clearly spelt out that the central government delegated powers to the regions, but also included measures such as the centre's veto right over regional regulations and budgets, effectively returning key powers to the centre. The laws of 2004 marked the end of the 'high season of regional autonomy' (McCarthy 2007). However, in exchange for this increase of central oversight, and clear recognition of the idea of a unitary state, the laws of 2004 also set up the process for direct elections of governors and district heads. This built in a counterbalancing long term commitment to representation, accountability, and acknowledgement of the legitimacy of regional governance (Crouch 2010). The overall effect of the 2004 laws was to restore to the centre power and responsibility in matters administrative and fiscal but in exchange for greater political decentralisation .

Despite considerable attention focused on the revival of *adat* in Indonesia in the period of *reformasi* (Davidson and Henley 2007), its application as a part of central government forestry decentralisation since the *reformasi* has been weak. This is consistent with a shift in the rationale for decentralisation from maintaining culture and ethnic identity to economic efficiency (Rodríguez-Pose and Sandall 2008). Through the *reformasi* period there were many localised examples of logging companies being required to work with local communities as well as increased local community actions in support of *adat* and customary tenure claims (Barr et al. 2006e). In 2006 regulations provided for allocations of Indonesian forests to community-based forest management, however, some years later such measures were still considered to remain at the margins of forestry policy despite clear evidence of their job creation potential (Royo and Wells 2012). Perhaps most significantly for the revival of *adat* and customary tenure, in 2013 the Indonesian Constitutional Court found that the 1999 Forestry Law did not override pre-existing customary tenure and *adat* in state forests (Johnson 2013). The ramifications of this are far-reaching, involving ownership of millions of hectares of forest—in 2015 the government moved to reallocate 12.7 million hectares of forest to local forest communities while leading indigenous rights groups talk about making claims for many more tens of millions of hectares (Astuti and McGregor 2016).

Another recent development is emerging international pressure over the role of forests in climate control and biodiversity protection, creating another driver for central control. This has expressed itself in Indonesia through moratoriums on the issuing of concessions on peat and primary natural forests since 2010 (Murdiyarso et al. 2011) and the development of REDD[61] projects.

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61 REDD (Reducing Emissions from Deforestation and Forest Degradation) is an initiative of the United Nations Framework Convention on Climate Change to reduce emissions from forest changes by facilitating payments from developed countries, corporations and non-government organisations for reduced emissions from forest changes in developing countries (Phelps, Webb, and Agrawal 2010).

What can be seen from the above is that over the course of Indonesia's development the process of assembling and controlling the territory of Indonesia as a state was a strong centralising force—the long history of Indonesia is one of increasing centralisation consistent with the concentration of power in the nation state. Forestry and forest use and management have played a significant part in this.

7.4 The effects of decentralisation on governance in forestry

The review above suggests that application of decentralisation to date, including in the *big bang*, was primarily an instrument to further territorial control during periods of weakened central government by appeasing separatist agitations. Demand for decentralisation appears in the colonial discourse in the early twentieth century (Vlekke 1959) in logical response to the emergence of the centralised state. Dutch attempts to create a federation at the end of their rule were seen as a ploy to keep a level of power and influence in the regions that would not be possible in a unitary state of Indonesia alone (Crouch 2010). This highlights the use of decentralisation as a tool of power wielded by a central authority to maintain central control. This use of decentralisation, for essentially central government aims, could well explain the initial failures of the *big bang* in forestry. At a governance level, for example, assignation of responsibilities to districts rather than to the provinces which were more strongly associated with separatist and identity based struggles (Ribot, Agrawal, and Larson 2006), is an obvious source of potential failure. At the district level, a lack of capacity to implement good forest governance contributed to problems that gave justification for the centre to reinstate its control.

Overall, there was poor implementation of *Otda* law (Arnold 2008), and 'weak governance structures' in general (Gregersen et al. 2005). The idealistic drivers of reform struggled to be realised as they collided with Indonesian power conflicts and the essentially political motives behind *Otda*. Vedi Hadiz notes that 'entrenched local predatory interests' effectively co-opted externally driven efforts to impose good governance for their own ends (Hadiz 2010). The extension of 'money politics' to the periphery was reflective of this failure to realise the aspiration of decentralisation as a tool to undo the corruption of the previous centralised regime (Crouch 2010), and despite the democratic promise of decentralisation it acted to decentralise corruption as well (Malley 2003). At the end of the New Order the Indonesian state 'had become the possession of its own officials' (Hadiz and Robison 2013). It follows, then, that the *Otda* which transferred those officials to the regions simply rearranged the geography of the ruling class. It failed to undo their control over the state. Fukuoka (2013) describes how, when a 'sultanistic regime'[62] democratises after its collapse, it can still be prone to the same clientelist patterns of power relations. In this sense, like corruption being decentralised, the patron-client relationship of the sultanistic regime was decentralised. Likewise, the oligarchic nature of Indonesia under Soeharto was continued in spite of *Otda* (Hadiz and Robison 2013). In this, then, the promise of the radical state institutional rearrangement of *Otda* struggled to be realised, because it was prone to many characteristics of the preceding centralised system.

The radical changes of *reformasi* also failed to address issues of poor property rights. These had been in limbo since the early promise of fairer land distribution in the Basic Agrarian Law had been brushed aside in the New Order period,

[62] Fukuoka uses the term to generically describe rule by a non-ideologically driven ruler using personal following to wield power, rather than the traditional Indonesian association with historic sultans and their re-emergence as part of *adat* revival. See Van Klinken (2007) for discussion on the latter in particular, and its relationship to the concept's utilisation by Fukuoka.

tarnished by its initial association with the Communist Party (McCarthy 2000). Control of forested land by the centre under the Forestry Law of 1967 allowed the Soeharto government to transfer rights over forests to a small number of large private interests closely aligned with Soeharto himself, while using the discourse of leviathan forestry as justification (McCarthy 2000). The long history of increasing central control of Indonesia's forests by the institutions of professional forestry and centralised government corresponded with a decrease in local access to, and use of, *adat* (Peluso and Vandergeest 2001). In addition, traditional systems of forest management were also vulnerable to breakdown in the face of rapid social and technological change (Dietz, Ostrom, and Stern 2003). The disruptive influence of colonisation, and central government appropriation of traditional forests and their use from customary owners, can lead to the 'tragedy of invasion' (Brightman 1987). In Indonesia's case, the tragedy has continued after the invasion of colonisation ended.

In the contest between *adat* property rights and those of the state, demarcation of forests through mapping has also been essential to the assertion of territorial control by central government forest agencies (Peluso 1995). The Dutch first used mapping as a tool for control of Java's forests in the nineteenth century and subsequently the Forestry Laws of both 1967 and 1999 asserted control over extensive forests through their associated maps. In May 2014, in a speech in Jakarta, President Susilo Bambang Yudhoyono noted the current unified Indonesian mapping project he himself had initiated (Yudhoyono 2014). This mapping [63] is intended to provide greater clarity to central government forestry

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[63] *Inisiatif Satu Peta* or the One Map Initiative was formalised under Law No 4/2011 on Geospatial Information, Information Geospatial Agency. It is intended to provide Indonesia with a single mapping system from which all government agencies will base decisions in order to improve transparency and efficiency (Santosa, Khatarina, and Suwana 2013).

initiatives along with increased transparency. It is also argued that the ongoing refinement of mapping and clarification of land tenure will improve the ability to undertake community based forestry initiatives (Royo and Wells 2012). Here, then, there is the potential for this new mapping to contribute to 'counter-mapping'—use of maps to build counter-claims to the past alienation of territory by central authorities (Peluso 1995). The emergence of counter-mapping initiatives also indicates increased central government responsiveness to local and regional needs, including *adat*. This, along with recent changes in the legal standing of customary rights under the Forestry Law and other initiatives in community based forestry, point to a significant reshaping of the relationship between the spheres of interest. Here, it is speculated that a new paradigm for the relationship between spheres of influence is emerging—one that is based on efficiency, rights and sustainability rather than the power contest of the old paradigm (Figure 20).

The imposition of central government control over forests is consistent with a strong historical global current in the institutions of forestry. These were ostensibly developed to protect forests from overexploitation in a tragedy of the commons scenario, but often emerged as a result of power contests over use of strategic resources, including wood, hunting and land (Sayer et al. 2005). This alignment between forestry institutions and leviathan has been mirrored in the development of leviathan government tendencies in the modern conservation movement to protect natural areas (Sayer et al. 2005). This is consistent with ongoing impositions of centralised control over forests through mechanisms such as REDD and its related moratoriums on the issuing of new logging licences (Murdiyarso et al. 2011). However, there are also calls for decentralisation as an optimal method of delivering REDD (Karsenty and Ongolo 2012), including the need to recognise local and traditional rights

(Wright 2011). Such an approach would act to align local spheres of interest with national and international spheres. This reflects the possibility that new motives operating in the international sphere of interest could push the development of a more nested set of relationships between the various spheres of interest. Here, a shift could occur, from spheres of interest competing for resources and political power, to spheres of interest cooperating for mutual resilience (Figure 20). Drivers for the emergence of these more cooperative arrangements between the spheres of interest are increasing recognition of the importance of extensive and interconnected social, economic and ecological systems, new governance responses to this understanding and related shifts to delivering efficiency, rights and sustainability. REDD and its evolving implementation, as noted above, is a potential example of such an evolution.

In terms of evolving relationships between spheres of interest, unfolding changes in forestry could also provide opportunities for increased decentralisation. The growing volume of wood coming from plantations in Indonesia (Figure 8) could reduce pressure on natural forests for wood extraction. As noted earlier in this thesis, this has been suggested as a means to allow greater use of natural forests for such ecosystem services as biodiversity, where previously this conflicted with wood production (Sedjo and Botkin 1997). By the same logic, it could also potentially reduce conflict between revitalised *adat* forestry and the large commercial drivers behind concessionaire-based natural forest logging by shifting the bulk of the timber demand to more concentrated areas of intensive timber cultivation. This would allow extensive natural forests and adjoining agroforestry landscapes some respite from the centralising demands of highly concentrated and capital-intensive timber industries. This structural change in forestry could increase the prospect of a new paradigm of nested, or cooperative, spheres of interest to emerge.

An increasingly resilient sense of Indonesian nationality could also provide the central government with more capacity to relax its control over forests (territory), providing another opportunity for increased local control where that is consistent with best outcomes. Finally, the arrival of a more democratic society in Indonesia has allowed the emergence of new coalitions urging localisation of power over natural resources. For example, environment movements and local political interests have allied against the central government—despite clear differences in their views—to seek a shift in decision making away from the centre (Kimura 2010). This exploration of possible alignments between different spheres of interest provides opportunities for the discovery of synergies that might facilitate cooperation between spheres of interest rather than contest. It is possible that in this environment of cooperative spheres of interest that a lasting and effective decentralisation can emerge. That is, in complex interconnected socio-ecological systems decentralisation has a supportive logic based on building system resilience for long term delivery of efficiency, rights and sustainability. By contrast, in a contested spheres of interest paradigm dominated by power relationships it is likely that the interests of the national sphere will remain separated from local sphere interests and tend to draw power to them, in the logic of maintaining power.

7.5 Decentralisation into the future

In relation to Indonesian forestry, *big bang* is something of a misnomer. Over the longer sweep of Indonesian history the development of the Indonesian state has been mirrored by the rise of increasingly centralised forestry governance. Even in the brief period of the 'high season of regional autonomy' (McCarthy 2007) between 1999 and 2002, forestry was much more centralised in Indonesia than at any time prior to independence, with a centralised bureaucracy having far-reaching powers across the archipelago. While parts of Indonesia had relative decentralisation in forestry during some of this history (for example, in the years after the 1957 regulations set up a parallel forest bureaucracy in the Outer Islands) these periods were generally associated with little or no commercial or strategic interest in the use of forests. Where commercial or strategic value developed there has been an associated move by the centre to quickly claim rights and responsibilities over relevant forest resources, such as the regulatory recapture of power that occurred in the early years of the New Order.

In the case of the *big bang* the dramatic decentralisation of the 1999 laws was quickly limited by the new Forestry Law of the same year, and regulatory refinements of 2002 and 2004 further limited the devolution of forestry governance to the regions. The reality of decentralisation of forestry in Indonesia, in the intensively studied years after 1999, does not support the idealised benefits of greater equity, increased wealth, and more sustainable forest management. Instead, this can plausibly be explained through the poor implementation of *Otda* in forestry; it was far from comprehensive and rapidly and substantially reversed. Regardless, the major forest allocation decisions relating to the predominant large-scale wood concessions and related capital-intensive wood processing facilities, along with control of forests for carbon and biodiversity conservation purposes, has essentially remained with the central government. Despite this, there is evidence of an emerging decentralised forestry potential through increased support for customary forest management. In addition, reductions in corruption and increasing democratisation could raise the ability of local spheres of interest to be more effectively involved in forest related decision making. This is critical to realising the benefits of decentralised and *adat* forestry in Indonesia, where many of the rural poor live with forests.

In 1983 Diana Conyers asked if the emerging wave of interest in decentralisation was a repeat of earlier phases in the 1950s and 1960s and, as such, a reflection of a periodic pendulum swing between the two, or a result of a more fundamental change in governance (Conyers 1983). In the case of Indonesia and forestry it seems the *big bang* reforms contain elements of both. Shifts between centralisation and decentralisation have continued to occur, especially in response to contests over power between the centre and regions, reflecting the pendulum effect—Siswanto and Wardojo (2005, p. 74) note that '[s]ince independence in 1945, the governance system has changed no fewer than six times, back and forth from centralised to decentralised'. This could be seen as a logical outcome of a contested spheres paradigm. However, given the almost total centralisation that occurred under the Soeharto regime, it also seems likely that, providing the democratisation of Indonesia continues with a higher degree of local participation in decision making, the emerging decentralisation measures may reflect a fundamental and lasting change, with potential for greater say and benefits going to local forest communities. In particular, there is the opportunity to deliver international, national, and local concerns in an integrated fashion through building cooperation between them.

Forest ownership in Indonesia, as in much of the world, continues to be dominated by central government. However, also replicating global patterns, control of government-owned forests is changing in response to demand for increased local and traditional management, private control through concessions and independent certification (Agrawal, Chhatre, and Hardin 2008). There is also a need to recognize the presence of ongoing structural evolutions in forestry – these require governance that is adaptive to changing conditions (Dietz, Ostrom, and Stern 2003). By allowing greater flexibility between formal ownership, as determined by Indonesia's forestry laws, and control and governance of forests, there is increased scope to find a more nuanced governance structure suited to the demands of Indonesia's forests and dependent communities, with polycentric spheres of mutually supported interests. This means that the promises of decentralised forest governance might be delivered, not as a central government-ordained *big bang*—but rather, as a progressive, paradigmatic evolution.

This complex unfolding of change challenges the notion of socio-ecological system, as systems that will suddenly 'flip' between basins. Even in the case where the events leading up to the *reformasi* were suggestive of a rapid system change, it becomes clear that as the implications of such change reverberate through the social, cultural, political and economic systems, they meet with much resistance and encounter points where there are tendencies for old patterns to reassert themselves. This, then, becomes an important pointer for understanding change in wood/forest socio-ecological systems as studied here—that is, to understand that change between basins occurs more as a progressive, paradigmatic evolution, rather than as the 'flip' suggested in resilience thinking.

8 A discursive turn: foresters' speak, and transitions in New Zealand

In conventions of discourse,
In the elaborate knit of language,
Power conceals its sly face

(Hay 2016, p. 121).

8.1 Introduction

This third national case study is of New Zealand. It assesses the model of change outlined in Part 2, the transition of wood/forest socio-ecological systems through distinct basins of attraction. The inquiry uses a blend of discursive analysis and quantitative text, or content, analysis. It does this with two research questions in mind. Firstly, it seeks to consider how effective the resilience and basins model is in describing change in social-ecological systems. Secondly, it builds on the analysis of the institutions of forestry from earlier chapters by considering what the changes identified in the journal writings says about the institution of the professional forester.

It does this analysis by using a corpus of writing of professional foresters in New Zealand over the 87 year period from 1927 until 2013 found in the national professional institute's journal. Until 1936 the journal was published as *Te Kura Ngahere* which started in 1925 in the Canterbury College of Forestry (New Zealand Institute of Forestry 2015). It became the official journal of the New Zealand Institute of Foresters from 1934 (in 1988 the Institute renamed itself the New Zealand Institute of Forestry). From 1937 the journal was named *The New Zealand Journal of Forestry* (between 1986 and 1998 it went by the shorter name of *New Zealand Forestry*).

When the journal commenced, New Zealand was fast approaching the limits of its natural forests for wood provision and was developing stewardship forestry institutions in response (Fleet 1984; Roche 1987). The journal was an expression of the emergence of the stewardship forestry basin; of the establishment of formal institutions intended to bring about sustainable wood production from New Zealand's forests. Over the subsequent decades forestry in New Zealand transited through a period of stewardship forestry in its existing forests to an intensive wood cultivation based almost entirely on plantation sources. The shifts in wood production from natural forest exploitation to cultivated wood sources can be seen in Figure 8. New Zealand reported 2,090,000 ha of exotic tree plantations in 2011 and 8,063,000 ha of indigenous forest ecosystems (FAO 2014). Plantation sourced wood has gone from being close to zero per cent of wood supply in the 1920s to almost 100 per cent now. In addition, New Zealand now produces volumes of plantation wood in the order of twenty times greater than its natural forests were producing at their peak 60 years ago (Figure 8). A near complete transition of wood production from natural forest exploitation to wood cultivation has occurred. Given this, the writings in the journal are a potentially rich data source for understanding the transitions and basins in the wood/forest socio-ecological system.

This analysis sought discursive reportage of changes in the basins and also of the resilience of basins and resistance to change. It also looks for evidence of discussion that implied recognition of fixed states (stable basins) and stressors that were forcing potential change on those systems. Finally, it considers how tensions over the pursuit of new technologies and change, and shifts in social values, were reconciled with forestry's core aims of sustainability and creating stable systems in equilibrium.

Discursive analysis approaches text as the site of social actions (Wetherell 2001). This work looks in particular at the social actions of key actors, specifically foresters, in the wood/forest socio-ecological system. Wetherell (2001) provides three useful approaches to thinking about discourse analysis as a way to understand social phenomena. Firstly, she refers to *correlation*. This is noting language that is a reflection or response to social circumstances. Second, there is *choice*, the illumination of a writer's choices of words and their intention to convey selected meaning. This approach seeks to understand the influence of the writer (speaker) on their social environs, not merely its correlation with the social. Finally, there is *critique.* This is where the analyst, following the logic of *choice,* asks of the discourse what choices did the writer make, and perhaps most usefully, why? Wetherell observes that power relations in particular can be studied in discourse analysis, and Van Dijk (2001) also stresses the importance of addressing power relations in a critical discourse analysis. To some extent, the role of power relationships between different interest groups in the development of the stewardship forestry basin was addressed in the previous case study of Indonesia. This chapter, seeks to broaden this by illuminating the struggles of forestry professionals. It considers how they confront change to the wood/forest socio-ecological system.

There is a small body of discourse and content analysis related to forestry. Findings tend to focus on conflict and change in forestry systems and how key groups have deployed language in order to affect (or deflect) change (for example Bell 1995; Hillier 2003; Wolf and Klein 2007), although Xu and Bengston (1997) take a correlation approach, analysing the language for markers of change in forestry in the United States. Taking its cues from this literature, the approach taken in this chapter was considered likely to prove a valuable method of inquiry. It is possible that the limited body of literature on such reflexive analysis arises from a combination of the deeply pragmatic nature of the forestry endeavour and a concomitant acceptance of the rationale for stewardship forestry as self-evident. And yet, as has been outlined in this thesis, the circumstances in which a social institution might arise are subject to all manner of change. Thus there is likely to be considerable value in an enquiry such as found in this chapter, especially as it might reflect on the seemingly self-evident.

8.2 Methods

The *New Zealand Journal of Forestry* is a suitable historical document to study, containing, a mix of written content including peer reviewed articles, letters to the editor, and editorials. These traverse a period of significant change in forestry in New Zealand. All editions of the journal from 1925 to 2013 are freely available on the New Zealand Institute of Forestry website—http://www.nzjf.org.nz/. The software program, Backstreet Browser, was used to download these PDF (Portable Document Format) files from www.nzjf.org on 21 July 2014 (21 June 2016 for the 2013 edition). PDF files were sorted by journal issue and checked for searchability. Those that were not searchable were made so using optical character recognition in the software Adobe Acrobat PRO. The journal was arranged on the web with each article of each issue in a separate PDF file. After the PDF files were made searchable they were combined into a single file for each edition. In most cases this meant that each merged edition then had multiple duplicate pages where pages included the start and end of two or more different articles. Each edition was checked for these and they were deleted in Adobe Acrobat Pro.

To limit the corpus size to keep the analysis manageable, but give effective time coverage, just one edition from each year was selected. Until the mid-sixties there was only one edition. From 1964 the journal started producing two issues a year. The first issue aimed to 'contain as wide a variety of papers on forestry as we can secure', while the second was focused on papers from the Institute's annual symposium (Jackson 1964, p. 6). Based on this the first edition for each year was selected as it indicated a wider range of themes and lower risk of special themes influencing the results. From 1986 four issues were published. The editorial at the time spoke of seeking a wide range of articles with no particular issue focused on special content or issues (Mead 1986). Therefore, in keeping with the previous period, issue number 1 from each year was chosen. All up 87 journals, one from each year of an 89 year period, were selected for the corpus (the journal was not published in 1942 and 1943, presumably due to the interruption of the Second World War).

The corpus was analysed using a coarse coding method in the software NVivo. NVivo also allowed some simple quantitative analysis. Based on prior thesis research the following codes were used as a beginning: agriculture, balance, biodiversity, climate change, conservation, ecosystem service, export/import, fibre, genetics, natural forest (or the New Zealand equivalent—indigenous forest), plantation, planting, resource, soil nutrition , stewardship, sustainable, technical forestry, technology, timber, wood. This list was expanded through snowballing as the coding was done.

Part way through this analysis a visiting scholar recommended text analysis software, TXM (for details see Heiden 2010), and supported its installation and operation. It provided a number of additional computations not available in NVivo. This involved batch conversion of the PDF files to text files before importing them into TXM. During analysis with this software it was discovered that more than a dozen of the journal editions used still contained duplicate pages missed in the initial manual search. To improve the accuracy of the text analysis each of the 87 text files was processed with the software program, Duplicate Finder, which had an automated process for removing duplicate lines of text. Subsequent checks and analysis found no more duplicate lines of text. It would, however, have removed lines of text such as titles, page or section headings, footers and headers where they were identical and repeated within a single edition. It is not considered this would have been detrimental to the accuracy of text analysis of the main articles; rather, it would have reduced the potential bias of the quantitative findings due to these repeated lines of text. In TXM a specificity test[64] was run on the corpus. In order to smooth out potential noise from single issues or even articles within an issue the corpus was partitioned into 18 five year blocks (note that 1940-44 only included 1941 and 44 and 2010-14 did not include 2014).

It was also found that the optical character recognition did not accurately interpret all words. Based on a course random sampling it was estimated around 1 per cent of words were errors—that is, the optical character recognition failed to interpret the word correctly in about 1 in 100 cases.[65] In total the corpus contained 4,063,681 words and manually correcting them all was not feasible. It was not considered that these errors would alter the broadly observed trend patterns used in the analysis here. The data generated by TXM were further analysed in MS Excel. Of the 52,817 different words[66] 49,277 that had less than 100 occurrences of the word in the corpus were removed in an initial shortlisting.

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64 Specificity is a statistical measure of the frequency of a particular word's occurrence within a part of a corpus and how that deviates from its occurrence across the whole corpus (Drouin 2004).

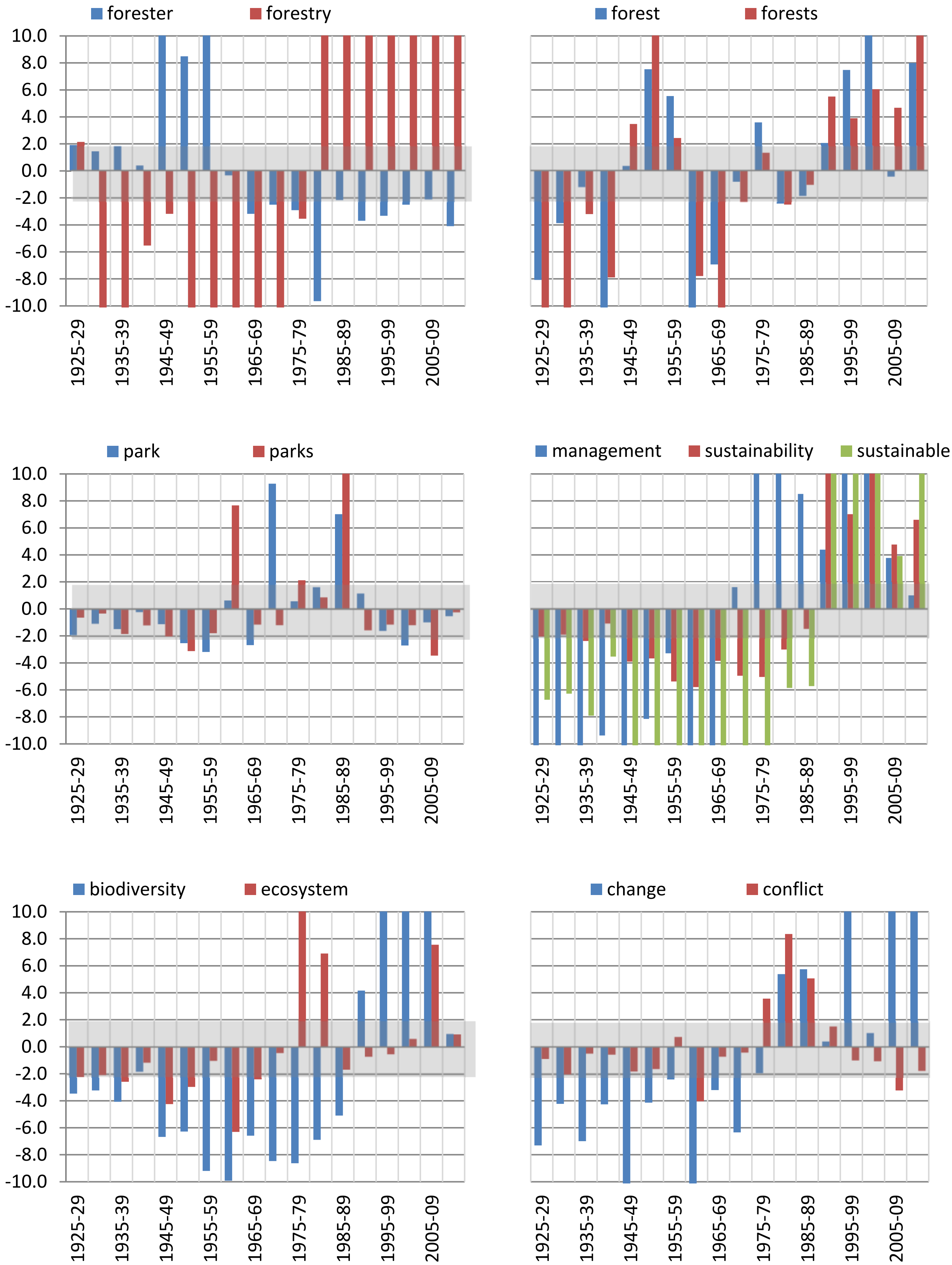
65 The most likely source of errors would be poor quality scans. A check using a random selection of 453 error terms found them distributed across the corpus with the periods 1930-34, 1940-44, 1945-49, 1975-79 and 1980-84 having above average levels of error terms.

66 A 'word' here is a particular set of case specific letters. So, for example, *Forestry*, *forestry* and *FORESTRY* are each treated as separate 'words' in this count.

From the remaining results dates, numbers and symbols were removed. A manual selection of words considered most relevant to the process of change in forestry systems (mostly nouns based on the previous coding) was made. This selection was analysed with colour coded conditional formatting to highlight patterns of change (see Appendix C for results in full). Excel was used for the generation of graphs included in this chapter. Finally, there was some iteration between NVivo analysis and TXM text analysis where findings and insights from one were used to inform refinement and inquiry in the other. This included using *concordance* (a display of words to the left and right of specified terms that show the words context in text) and *co-occurrence* (the frequency and average distance [measured in number of words] one word occurs with or near another) functions of the two software packages to further interrogate the discourse.

8.3 Results and analysis

Using the method outlined above a heuristic approach was taken which involved following particular words that displayed distinctive trends which were considered of importance to the phenomena studied. The following section presents these key words, describes the quantitative findings and then draws on text examples and qualitative analysis to further consider meaning and insight that these changes in word usage might indicate. The graphs on the following pages (Figure 22) show the specificity results from TXM of these words. The section has been structured starting with *forestry*, the word denoting the central institutions of the stewardship forestry basin. It then looks at *sustainability*, a term that describes the guiding stewardship forestry logic. This in turn leads to an exploration of two tensions acting on the stewardship forestry basin—increasing demand for non-wood values and technological and economic drivers towards increased efficiency, production and intensification in wood production.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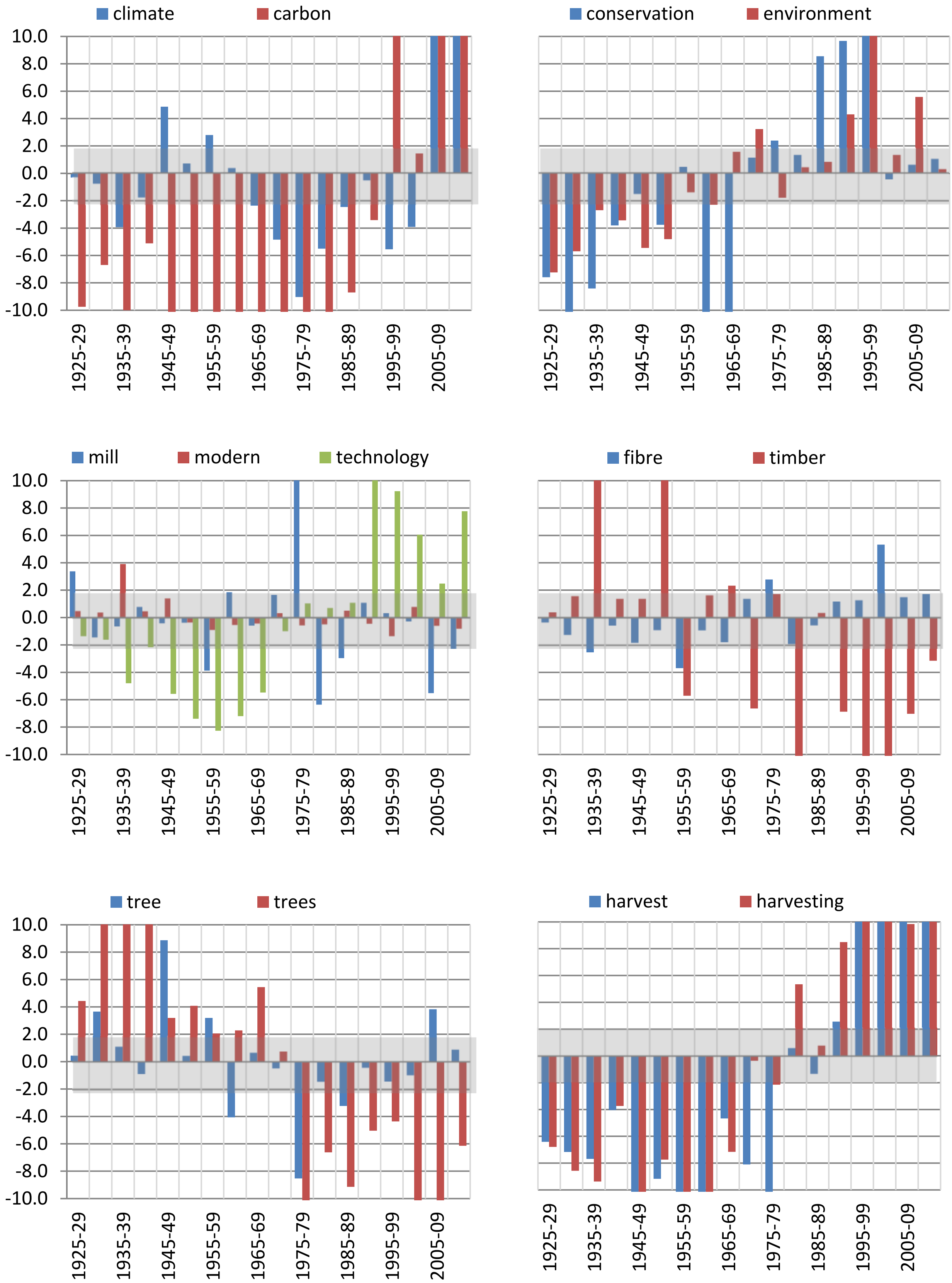
1935-39
1945-49
1955-59
1965-69
1975-79
1985-89
1995-99
2005-09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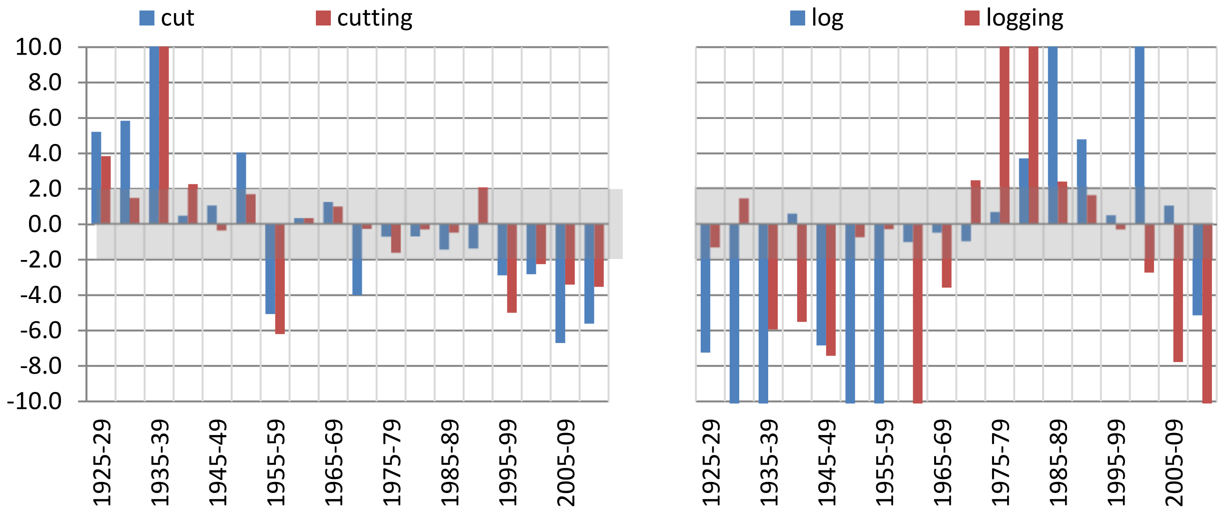

Figure 22. Specificity results from TXM of selected words noted in the following discussion.[67]

The word *forestry* had a positive specificity from the 1980s onward despite being the central idea of the journal across the period. Why was *forestry* written so much more often at the end of the period? One possibility is a change in audience. If the journal was originally written by foresters for foresters, then, maybe, things that were *forestry* would have been assumed self-evident. A discourse could occur within forestry that has no need to refer to itself if the writer and reader are clear that they exist within forestry. If, though, the audience became more diverse later in the journal's publication period, there might be a greater need to declare matters as *forestry*. Another possibility is that this change could indicate a defensive claim to the conceptual territory of *forestry*. It might, for example, be that the profession felt a growing need to press its case, '[t]he imperative need for the forestry sector to use its own tools, and

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[67] To better show the detail of lower specificity scores the graphs have limited the y-axis to between 10 or -10. For details of instances of specificities that go beyond these graphed limits see Appendix C. Specificities between 2.0 and -2.0 are not considered statistically significant and are shown by the central greyed range in graphs.

publish its findings is now clear' (Holloway 1983, p. 6), including to governments: '[h]owever, there is a hands-off attitude by the government to production forestry which is mirrored in the government departments' (Goulding 2013, p. 44). Or, it may stem from a felt need to defend or explain itself to an increasingly critical public: 'there is an urgent need to challenge much of the negative comment about forestry 's contribution and its future potential', said Wink Sutton, the new president of the Institute (quoted in Anon 1988, p. 26). It could also represent the maturity of *forestry* as an idea, through the growing pressure to encompass non-wood values in forest management.

In 1988 the New Zealand Institute of Foresters changed its name to the New Zealand Institute of Forestry (Halkett 1989). Nevertheless, the increase in use of *forestry* is not likely to have been caused by this as the specificity analysis above excludes the form *Forestry* with a capital *F*. But, the change in organisational name might best explain the changes in use of the word *forestry* more generally. Certainly, a shift in discourse in the journal from being about the profession of foresters to about the management of forests more broadly would also support the notion of a change in audience, as well as a change in approach, from a singular focus on wood production to a wider range of non-wood values. Again, this could in part be a defensive reaction to a growing social critique of stewardship forestry forest management. The President's address in 1982 (Rockwell 1982, p. 23) notes the Institute's mission was 'considerably widened' from the historic 'further the development of forestry' and 'interest of the profession', to, promoting 'the best use of New Zealand's resources', encouraging 'wise use of forests and forest land', as well as supporting the profession. This indicates the widening of concern beyond the profession. The shift in emphasis from *forester* to *forestry* in the name of the Institute attempts to embrace this and reflects the greater range of values expected from forests—beyond wood.

Sustainability of wood supply was the motivating consideration of the stewardship forestry basin (see Part 2). It was expected then that the words *sustainable* and *sustainability* might both feature in early discussions, nevertheless, both showed a pattern of positive specificity in the period from 1986 onwards (and negative before). *Perpetuity* is another word that might be associated with these ideas but, again, it only appears twice in the 1940s before becoming prominent thereafter. Like *sustainable,* it is not correlated with the emergence of the stewardship forestry basin. *Sustained,* another word that conveys this ongoingness, does occur almost as often as *sustainable,* but, its use across the corpus is more widespread, with a pattern of lower use in the earliest and latest years only. An obituary for Leon Macintosh Ellis (Anon 1944, p. 7) identifies, as one of his main achievements as first Director of Forestry, the legislation that secured 'the basic land requirement of all forestry—permanency of use and tenure'. It is clear that sustainability as it is now considered was the goal but the term itself came into use only as part of the process that became a source of tension and challenge to the wood supply logic of the stewardship forestry basin.

Specifically, *sustainability* and *sustainable* become widely used from the end of the 1980s. The rise of the use of *sustainable* is consistent with its application in the context of a broader global rise in the social awareness of environmental issues (Dunlap and York 2008). In this case, the word *sustainability* is associated with the rise of the concept of forests as ecosystems that deliver a diverse range of services and values, rather than just as a source of ongoing wood supply. This is likely to be associated with the rise in sustainability thinking that emerged globally after the Bruntland Commission's 1987 report *Our Common Future* and the Rio Earth Summit of 1992 (Mebratu 1998). In this sense, while forestry had clearly pursued what is now considered *sustainability* in wood production, it embraced the term only in response to the emergence of sustainability within the global environmental discourse. Again, it is also possible that this reflects a need to defend the work of forestry in an environment where it was now often under attack.

Usage of the term *management* increased from the 1970s until an apparent tapering toward the end of the period researched. Key co-occurrent words for *management* included *forest (forests), sustainable, practices, indigenous* and *planning (plan)*. The concordance (within 11 words) of *management* and *sustainable* is 191 times, but only from 1991 onwards. The term *sustainable forest management* occurs 55 times from 1993 onward (never before). In most cases the term is followed by words denoting its bureaucratic integration; for example, *plan, rules, criteria, standards,* and *framework*. Reflecting the rise of sustainability in the development discourse noted above, the 1993 Forest Amendment Act included requirements for sustainable forest management plans. So, for example: '[t]he Act … permits the export of rimu and beech sawn timber, provided it is harvested under a registered sustainable forest management plan, or a sustainable forest management permit' (Baddeley 1993). This broader shift in use of the term *management* may also reflect a shift in the nature of forestry to one that is more managerial. This could indicate an increasing managerial turn in western society generally over the same period, that would be indicative of such panarchical processes as globalisation, industrialisation and technological innovation.

Park and *parks* have a high level of specificity in the 1960s to 1980s, but most noticeably in the period 1985-98. The term *conflict* also surges in usage in the late 1970s and 1980s. This was a period when the political debate about natural forest logging was leading up to its eventual cessation around 1990. However, the debate between ideas of protecting natural forest from logging and managing it for timber production had been occurring for some time. The journal editor (Anon 1946, p. 173) writes of the controversy over Waipoua State Forest:

> *[t]he article notes a school of thought born of the sentimental reaction to the pioneering phase of forest destruction which in its extreme form regards the preservation of all indigenous forest in its existing condition … as a desirable objective in all circumstances. These zealots of "preservation by non-use" … hold their beliefs with irrational and unyielding depth of conviction.*

While then acknowledging some legitimacy to these demands, the editor went on to caution that these claims 'must be kept in proportion if all attempts at silvicultural management of our indigenous forests are not to be frustrated'. In 1976 Leslie (1976, p. 6) noted that:

> *[i]t is not so long ago that forestry was in the forefront of the conservation movement. Now it has become one of the prime targets of the movement. Somewhere over the last two decades forestry and conservation parted company.*

The change to forest ecosystem management can be clearly seen in the upswing in usage of the terms *biodiversity*, *conservation* and *environment* from the 1980s onwards. The new non-wood demands on forest management were a source of discourse within forestry:

> *at no other time in our history has the value of forests been so highly recognised. Nevertheless, governments world-wide are struggling to come up with the right set of tools to value forests for their carbon sequestration, clean water, human environment and biological diversity* (Charteris et al. 2010, p. 5).

Their increased usage is likely to reflect the growth in environmental awareness already noted. It shows a responsiveness of forestry discourse to the general increase in societal concern for these issues. The rise of concern about climate change and the role of forests in mitigation and adaptation are reflected in changes in key words over time. Indeed, the term *climate change* occurs 182 times, with only four occurrences before 1990 and then in relation to prehistoric and historic climate change. The rise of the use of the word *carbon* is a most dramatic reflection of interest in climate change. In the last few decades it has become a significant concern for foresters in New Zealand, as reflected in their language.

The term *change* was used more than twice as often from 1980 onward (see the end of Appendix C for details), after its use as part of *climate change* was discounted. Foresters in New Zealand wrote *change* more often in this period, even without the rise of climate change concerns. The first part of this increased use of *change* coincides with the period in which there was considerable public discussion about the type of wood/forest socio-ecological system the country should have. In the 1980s there was considerable discussion about the cessation of logging within public natural forests. Towards the end of the decade the decision was taken (not as one decisive policy change but through a series of policy developments over several years) for New Zealand to make a transformative state change—out of the stewardship forestry basin to one of forest ecosystem management and a geographically distinct wood cultivation.

One of the significant shifts in wood processing technology observed in this research is the trend to composite wood products—the breaking down of wood into smaller parts and reconstituting them into the required product. This breaking down is done by sawing, peeling, flaking, chipping and pulping. In the process of researching this work the use of the word *fibre* in relation to wood was observed, and it was speculated that its use had increased over time, reflecting changes in how wood is sourced, used and valued. Of the three case studies New Zealand is the most wholly progressed on the transition beyond stewardship forestry and had reached a point where the institutions of wood production had significantly shifted to those of cultivated wood management. Technologically this change was exemplified by the organisational realignment of the key national forestry research body, as noted on their website:

> *[t]he New Zealand Forest Research Institute Ltd (Scion) is … focused on improving the international competitiveness of the New Zealand forestry industry and building a stronger bio-based economy. Scion has evolved from a company with a focus on the delivery of research, technology and service solutions to the forest and forest products sector to a company focusing on the entire field of plant biomaterials. The aim of Scion is to improve the competitiveness of New Zealand's forestry industry and advance the use of biomaterials* (Treasury 2015).

This description makes pointed reference to what it has been in the past. There is a sense of a need to explain the organisation's past. But why? Is it apology, self-consciousness, or does it aim to ensure the barely recognisable new language and mission is understood by those who identify with the 'forest and forest products sector'? Awareness of change and the transition is explicitly communicated. Scion's description talks of what it was, historically, and what it has 'evolved' into. It was an organisation that provided research and development services to the 'forest and forest products sector'. No longer is the talk of forest products (*timber* and *wood*), but of *biomaterials* and *fibre*. The statement indicates a significant evolution in how forestry and wood production is approached in New Zealand. This is reflective of the changes in the technology of wood processing and societal and market demands noted elsewhere in this thesis. What is striking here is the ability to talk about the industry in a way that is devoid of mention of sustainability and non-wood values. It suggests that when the natural forest estate is entirely managed by a separate formal institution, which is working on the agronomic cultivation of wood fibre, in landscapes clearly distinct from indigenous forests, they are able to more fully focus on the task of wood fibre and product production in a way that is relatively free of the need to manage forest ecosystems for non-forest values found in natural forest management.

Within the corpus studied here the use of *fibre* increased slightly over the period. Part of this could be a shift of usage. Where once *wood* would have been used, *fibre* seems increasingly the preferred term, such as in:

> *[t]here is also a move away from growing longer rotation, large trees by traditional, intensive management towards lower-cost, short rotation management for production of fibre. As such those countries which can produce short rotation wood and fibre will hold a competitive advantage* (Wijewardana 2005, p. 38).

It is also possible that the increasing use of *fibre* reflects the growing role of the pulp and paper sector within the wood products industry. As well as the use of *fibre* for increasingly sophisticated composite wood products, it is also more and more applied within the context of bio-products, as noted in the shift of emphasis undertaken by Scion.

Changes in the use of the word *technology* were observed, with it being used more in the later part of the period, specifically from the 1990s onwards. There are 31 instances of *new* and *technology* appearing within 11 words, mostly as *new technology*, though only from 1991 onwards, such as in: '[g]lobalisation and new technologies have helped the planted forest industry to respond … using new growing and processing technologies and producing new products' (Wijewardana 2005, p. 38). There appears to be a general recognition that technology is important to forestry and changing forestry. There is acknowledgement of new technologies in wood processing and discussion about the application of new technologies to forests practices such as in forest metrics (for example aerial photography, remote sensing, GIS and drones). These seem to be readily embraced. Technology is discussed as an opportunity and something to embrace—'[t]he ability of forest growers to benefit from adopting new technology in growing and processing' (Wijewardana 2005, p. 39), or, 'the need for new sophisticated harvesting technology developments and a skilled workforce' (Loughlin 1990, p. 16).

However, as might be expected, there are contrasting perspectives where technology is discussed as something that is to be approached with caution—'[t]here will always be risks relating to feasibility of new technologies' (Burdon 2008, p. 5), and '[o]f course, if we pursue … any other new technology, it must be done with great care and caution' (Moore 2001, p. 10). This is consistent with the tensions within forestry between a logic of tradition and timelessness that comes from managing forests as long term stable systems, and managing a socio-ecological system that is embedded in evolving and changing panarchic systems of modernity. The former sees tree growing and forest stewardship as an activity rooted in tradition (and therefore pre-modernity). Also, the draw of the traditional speaks to the struggles of foresters and their attempts to protect forests from the ravages of an expanding industrial society and then again, to protect those same forests from a rising social ecological impulse that would remove forests from the hard won stewardship of the forester. As the Forest Service faced restructure in the mid 1980s it was observed that it, 'retained a strong commitment to its traditions and long-term goals and was not receptive to the suggestions for change' (Halkett 1987, p. 20). However, tradition in the context of modernity within which stewardship forestry arises is problematic, 'for justified tradition is tradition in sham clothing and receives its identity only from the reflexivity of the modern' (Giddens 1990, p. 38). Foresters have this struggle then, being at once embedded within modernity, and at the same time, working against its expressions in wood/forest socio-ecological systems. In this, their experience is not unique.

It is possible that the shift of wood production from natural forests into a cultivated wood domain has allowed foresters some liberation from the management of a stable forest estate (groaning as it is under the ever-heavier weight of more and more demand to deliver non-wood values)—liberation to shift to a more technological, economically productive and modern focus. In such a shift technology can more easily be related to changing systems and, in fact, the modern. In the increased use of the words *modern* and *technology* there is, then, perhaps, an increased acceptance of change within the wood/forest socio-ecological system. This would be consistent with the increased use of the word *change* in recent decades noted above.

Not accidently, the phrase *technology transfer* also appears from the late 1980s onwards. As well as reflecting a rise in interest and acceptance of technology in general, this could also reflect a confidence in New Zealand in its plantation wood cultivation and a belief that it has something to offer the world. There are interesting parallels with Germany, where wood shortages led to the development of stewardship forestry and the technologies of sustainable yield management (see section 2.3 for details). As other economies around the world confronted the same problem of unsustainable resource use they, in turn, took on German forestry expertise. This process of international skills dissemination, then, became an element within national forester cultures. Jack Westoby (1970, p. 9), speaking as part of the New Zealand Forest Service's Golden Jubilee, spoke of 'the progressive insertion of New Zealand into the world forest and timber economy', and noted that:

> *the education of a forester is incomplete without some international experience. And the real gain from service overseas and from multiplying international contacts lies … in the intellectual cross-fertilization which enables the forester to think about his own problems in new and different ways and, in particular, to see them in the light of a world perspective* (Westoby 1970, p. 12).

Again, this clear international perspective points to forestry's immersion in the modern.

Finally, the three words *cut, log* and *harvest* were investigated. They demonstrate distinctive patterns of usage over the designated period. In their verb forms these words represent the basic wood production act—the conversion of living tree to inert wood. The terms *cut, log* and *harvest* and their derivatives show three distinct 'waves' of usage. *Cutting* is used most often until the 1950s, *logging* has a higher level of usage during the 1970s and into the 1980s, and *harvesting* becomes more common in the 1980s, though it appears rarely beforehand. What might these terms indicate of distinct phases of wood production?

Cut would suggest the finding and exploiting of wood from extant natural forests, as in 'for two sawyers to cut 50,000 feet of timber near Timaru' (Clark 1926). A feature of this phase of forest use is that wood getting is often entwined with clearing the land for non-forest uses such as settlement and agriculture. It is not just the tree that is *cut* for wood—the forest is *cut* to clear the land, often wastefully, '[t]here was no provision for any control of the licensee, who could go into any part of the district to which his license referred and cut and destroy timber without check' (Clark 1926, p. 22). There are numerous references to forest that has been 'cut-over'. In 1935 the Director of Forestry reported '[b]oth the remaining virgin stands and the cut-over areas carrying regeneration and advance growth are being brought under forest Working Plans' (Anon 1935)—the juxtaposition with *virgin* implying its existence as an alternative and new state to the pristine forest. Further, 'misgivings about the general handling of the indigenous forests', in New Zealand forestry are noted in an editorial review of the Summary Report of the Seventh British Commonwealth Forestry Conference of 1957, which lamented '[t]he rapid rate of cutting, the devastated condition of cut-over forests' (Poole 1959, p. 7). In addition to these notions of *cut* as a frontier exercise, cases of the word *cut* in the earlier years of the journal reveal that in many instances it is applied not just to the cutting of trees from forests, but of the *cutting* of logs into various products, as in a recounting of the activities of the School of Forestry's annual spring camp; 'tough English oak, sixty years old, to be felled and cut into posts; springy, gummy young pines … to be cut up for cordwood' (Anon 1930)

Logging as a verb has as its base word the object of the doing—the *log*. This would be a logical change in terminology for a stewardship forestry approach. The forest is no longer to be *cut*, it is to be retained. Only the log is to be removed, so wood-getting is now restrained to *logging*, rather than the more final, and now considered wasteful, *cutting*. *Harvesting* is the most recent of the three term to have a period of positive specificity. It is agricultural in evocation. Crops are *harvested*, forests are not. There is the emergence of crops of trees, although the term *crops* has its highest specificity in the period of the 1970s and early 1980s—at the start of the rise of *harvesting*. The most common co-occurrences for *crop* point to the word being used primarily in relation to trees (for example, *tree, trees, nurse [crop], rotation, thinning* and *radiata)*. The transition model described here would suggest that the new agricultural wood cultivation basin would be the logical place for the rise in usage of the word *crop*. The increase in the use of the word *crop* occurs at a time when pine production is growing rapidly in New Zealand, but before the emergence of growing concern for ecological considerations in forest management. As foresters increasingly tackle the public demand for non-wood values in forests, it is possible that a nascent conceptualisation of forest as crop was deemed incongruous with emerging notions of forests as complex natural systems, a view given additional impetus by a growing call for sustainable forest management. This might, then, reflect the wood/forest nexus being unravelled—an outcome of the tensions within forestry between managing forests as natural ecosystems and primarily managing forests as wood cultivation systems.

An alternative reason for the shift to the word *harvest* is a response to the growth of the environmental demands. If the conservation movement was successful in shifting public opinion against *logging* in natural forests, it could have been advantageous to shift the term to *harvest*—a word evocative of the more widely accepted process of growing food in monocultural crops, but also evocative of the *harvesting* of ,say, mushrooms or seeds from a forest—a largely benign undertaking. Perhaps *logging* had come to be seen as too harsh an intrusion into the forest while *harvesting* could be conceived as a acceptable part of managing a forest—an evocation of light touch wood removal that largely leaves the forest intact. This is a type of wood removal that retains the whole forest ecosystem as sought through ideas of sustainable forest management and other adaptive approaches.

The shift in terms could also represent a progressive shift to an increasingly technological form of converting trees to wood. To *cut* once is just to start the removing of a single log, while to *log* is to remove an entire tree's wood or even a section of a forest's wood in one act. It is an escalation of the impact over cutting, and potentially an irreparable impact: 'volume increments in more heavily logged forest are likely to be lower than in virgin forest and it appears probable that only small improvements in productivity could be achieved by silvicultural manipulation' (Smale, Bathgate, and Guest 1986, p. 16). *Harvest* can also imply the removal of a collection of logs in one act, yet has a primary association with the collection of annual crops: '[a]ltogether this group represents some 90 000 hectares of planted production forests with an annual harvest of some 1. 3 million cubic metres' (Anon 2002, p. 33). *Harvest* does more than *log*—it invokes a sense that the trees will grow back easily, naturally, reliably. A *cutter* cuts wood with an axe, a *logger* logs trees with chainsaws and heavy machines, while a *harvester* harvests trees with automated harvesters (indeed a *harvester* is commonly understood to be a machine, not a person). A wood *cutter* is evocative of an axe-wielding human. A *logger* invokes images of a hard hatted chainsaw wielder backed up with heavy machinery to wrestle with the logs once on the ground: '[a]ll the stands were logged before burning, usually by tractor and logging arch' (Childs 1961, p. 468). A *harvester* however, is a more generally associated with a machine that does the *cutting* and retrieval of the *log*. If there is a person involved it is an operator, someone who controls the machine doing the harvesting. The efficiency and extent of the impact grows with each change, but with *harvest* concerns about this are moderated through its more benign associations.

8.4 Discussion

The text analysis shows patterns of word use change that reflect the model of the transition from stewardship forestry to forest ecosystem management and wood cultivation outlined in Chapter 4. The use of words related to forest ecosystem values such as *climate*, *biodiversity* and *sustainability* all show increases towards the end of the period, reflecting the rise of social demands for these values in forests. In addition, terms such as *conflict* or *parks* peaked during the period of the 1980s and 1990s, coinciding with the period when discussion about the shift of wood production out of remaining natural forests was occurring. Attempts at adaptation within the stewardship forestry basin increasingly struggled with the transformative pressure to shift wood production to plantations alone. The evolving trend in the use of the words, *cut*, *log* and *harvest* is clearly indicative of the progression of wood production from exploitation of endowment forests through stewardship forestry to wood cultivation. The following discussion occurs in two parts. The first considers the implications of the above for the model of change described in Chapter 4. The second considers what this says about the institution of the professional forester.

As might be expected, the journal set up to represent the profession that existed to save forests from exploitation makes clear reference to the legacy of the exploitation phase. It was observed that some wood types were 'liquidated' to such an extent that attempts at sustainable forestry were simply too late (McKelvey 1987). Equally, the potential to remove natural forest from the foresters remit through protection in reserves was talked about many decades before the peak of the changes in this regard occurred in the 1980s. This is suggestive of a lack of neat transition in socio-ecological system states, a potentially significant limitation of the model of change postulated in this thesis—the theoretical model of change in biophysical systems posited in resilience thinking implies a complete flip between states, with one basin finishing as the other begins. Such representation is likely to miss the messiness of the shift from one basin to another in the sort of socio-ecological system described in this thesis.

As a further example, the discussion about New Zealand's shift to plantation and, hence, the wood cultivation basin in the early decades of the twentieth century, even while establishing a stewardship forestry basin, is telling. While some foresters worked to establish sustainable systems for New Zealand's natural forests others were working to set up a new wood cultivation regime. The annual reports of the first New Zealand Director of Forestry, MacIntosh Ellis, in the 1920s were said to 'reflect the natural instinct of the forester to rely upon the indigenous stands as his basic source of future timber supplies,' a stewardship forestry approach, 'and it was only with much reluctance that he abandoned this idea as an impractical solution to the country's future timber problem,' to became a champion of the major exotic pine plantation schemes of the 1920s in New Zealand (Anon 1944, p. 8). The passage quoted notes that even as the formal institutions of stewardship forestry were first established in New

Zealand there was recognition that the remaining indigenous forests alone were not capable of meeting future wood demands and that wood cultivation was needed. It might be, then, that the transition between basins is not a simple one of sequential transformation or adaptation, but the possibility that two basins of the same system can coexist during the change. One basin does not emerge into being after the other passes away; rather, different basins as states of the same system might coexist for a period, with one or the other coming to dominate at some point.

In part, this points to the panarchical nature of these systems and the arbitrariness with which we define them, as well as the simple state flip conceptualisation described before. However, the situation described here for New Zealand as a single wood/forest socio-ecological system suggests that for the period studied at least it is in a continual state of shifting between states, and never actually settling into a fixed stable basin. Here, then, the arbitrariness is not just in defining the socio-ecological system but also the particular basin. Finally, it can be seen that by defining the socio-ecological system at a national level we end up observing a system that is itself an amalgam of smaller socio-ecological systems. It is unlikely that all the socio-ecological systems within the larger one will exist at the same state at the same time. For example, if some districts have lost most of their natural forests but have considerable plantations, then the district as a discrete wood/forest socio-ecological system can be said to have transformed from one of stewardship forestry to wood cultivation. Again, we see the panarchy effects operating. Change in one district is likely to impact upon other districts—for example, through a transfer of knowledge or improved pine cultivars, or influences upon social/political dynamics.

This nesting of systems can be taken even further. As an example, the cited instance of MacIntosh Ellis as a single person who struggled with the logic of shifting to a wood cultivation basin while advocating a stewardship forestry approach for existing natural forests, can be seen as an embodiment of these tensions between states. This conceptual intergrading can also be seen in the overlap in skills and interests as forest management shifts from foresters to restoration ecologists and protected area managers. Indeed, Sarr et al. (2004) ask, '[w]here does silviculture end and restoration ecology begin? Are they different approaches on a continuum of management options, or do they represent different spheres entirely?' These questions point to the challenge of defining separate states, but the answers might also depend on the motives of the respondent and where they are sited in the contestation of visions and modes of description of socio-ecological systems. For example, foresters might be more inclined to answer that restoration ecology is just a recent adaptation of forestry thinking, while restoration ecologist argues for their distinctiveness. Certainly Sarr et al. (2004, p. 21) note:

> *that the primary distinctions between restoration ecology and forestry lie in aim and scope. Restoration ecology typically places ecological goals ahead of economic goals and poses different questions and treatments than most forest management approaches.*

As a central institution of the wood/forest socio-ecological system it is useful to consider what this analysis say about foresters—and, in turn, to consider what the discourses might say about the potential 'performativity' (Callon 2006) of foresters. Callon (2006) speaks of the performativity (of economists in his example) as being the way in which economics 'perform' markets; that is, how economists effect the subject of their study. MacKenzie (2006) notes that while it is obvious that economics will get used in economic practice, where it gets 'interesting' is when what he calls 'effective performativity' takes place. This is when the system itself (markets in MacKenzie's example) are affected by those who supposedly study the system as an object somehow unaffected by the institution of its study.

To what extent do foresters do this and, thus give their 'science' a performativity? Has forestry ever been a pure science with a capacity for objective distance from its subject? Or is it an applied science with explicit normative aspirations? The latter seems a more reasonable assessment, given the overarching imperative on which forestry institutions were founded—to produce sustainable wood supplies through effective forest management. In this sense the performativity of forestry as a science is less surprising then the 'outing' of economics by scholars of science (MacKenzie 2006). Instead, foresters always intended to alter the system they study. They have, then, been engaged in what Latour (1987) calls the task of *enrolling* others in a project in order to build its reality as fact. This in turn makes their task more clearly one that is political and socially constructive. It is clear that Foresters, as a profession, have always worn their normative aspirations on their sleeves, as it were.

Arts et al. (2014, p. 7) note that, 'in practice, the articulation or the enactment of discourse allows for constant modifications and adjustments. In other words, knowledge and reality constitute each other … one cannot be taken to pre-exist or cause the other'. Thus knowledge and discourses shape and inform socio-ecological systems, including their social institutions, which in turn act to inform and guide future knowledge production. This, in turn, raises the question: has the foresters' development at the nexus of wood and forests set up a performative role that acts to perpetrate this nexus, despite change in the state of the system? Have foresters acted to maintain the system in the face of pressures that would otherwise have changed it? The changing of the foresters' professional institute from an institute of foresters to an institute of forestry certainly indicates a recognition of the performative role of language. In this sense, their performativity is explicit.

The centrality of *forest* to forestry acts to set forestry's boundaries. But what happens when forests are parts of landscapes where forest intergrades with non-forest? For example, in conservation areas, it intergrades with grasslands, savannah, wetlands and other natural habitats. Where such forests are managed as part of diverse landscapes for non-wood values they are often not managed by foresters. It seems foresters must have forests. So, by definition, their work stops at the edge of the forest. And they must also have wood production from those forests. If they do not have these, then what is there to distinguish the forester from the conservation reserve manager, the natural resource manager, the plantation manager, the agronomist or the farmer?

Is it that, as New Zealand's natural forest resources diminished, the drive to shift emphasis to plantation came about in response to both limitations of natural forest and the role of foresters; that is having foresters in place, with their performative role—creating sustainable wood supply—informed how New Zealand responded to the impending wood shortage? And if this is the case, and foresters will pursue wood production out of forest ecosystems into agricultural ecosystems, then maybe *foresters* are really *wooders*? Kirkland (1984) observed that '[e]ventually the distinction between forestry, agroforestry and pastoral farming must become progressively eroded', and this analysis supports such a position. It can be argued, nevertheless, that foresters pushing notions of sustainability and care of forests might also have set the scene for forest ecosystem management for non-wood values. This might suggest that foresters could shift to extensive forest ecosystem management, but as noted above, this is generally not the case. Given this, the weight of evidence suggests that the forester and forestry (the terms are strongly tied) emerged to embrace the wood/forest nexus. This is now being undone. As a result, we are witnessing the emergence of a wood/forest socio-ecological system into a post forestry state.

Part 4: Contributions and conclusions

> *It is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be …* (Asimov 1981, p. 19)

This thesis has studied a process of change. It has reflected on an extensive literature, and identified clear trends. The following chapters will ask the question: So what? The value in doing this (beyond the potential for satisfying curiosity) is to understand what this might mean for wood/forest socio-ecological systems in the future.

Returning to the beginning of this thesis, there were three initial research questions. The first two, asking why is the transition of wood production happening? and, to what extent is it happening? have been considered in some detail in Parts 2 & 3. The matter of extent has been outlined in the research showing the level of change occurring at a global level. Results from Chapter 5 indicate the scale and direction of the trends in wood sourcing changes (Figure 23). As was noted, this global pattern reflects that shown in many individual countries, including the three case study countries. This represents a non-sustainable resource use pattern. In effect, the sustainability of global wood production is being achieved by an increasing reliance on cultivated wood sources. The focus on wood production into a smaller area of the world's forests is shown in Figure 24, indicating that a conservative 33 per cent of the world's industrial roundwood production was produced from the 3 per cent of the world's 'forest' that were production plantations in 2012. These productive plantations were nearly 18.7 times as productive as the world's natural forests and 2.6 times as productive as the world's semi-natural forests.

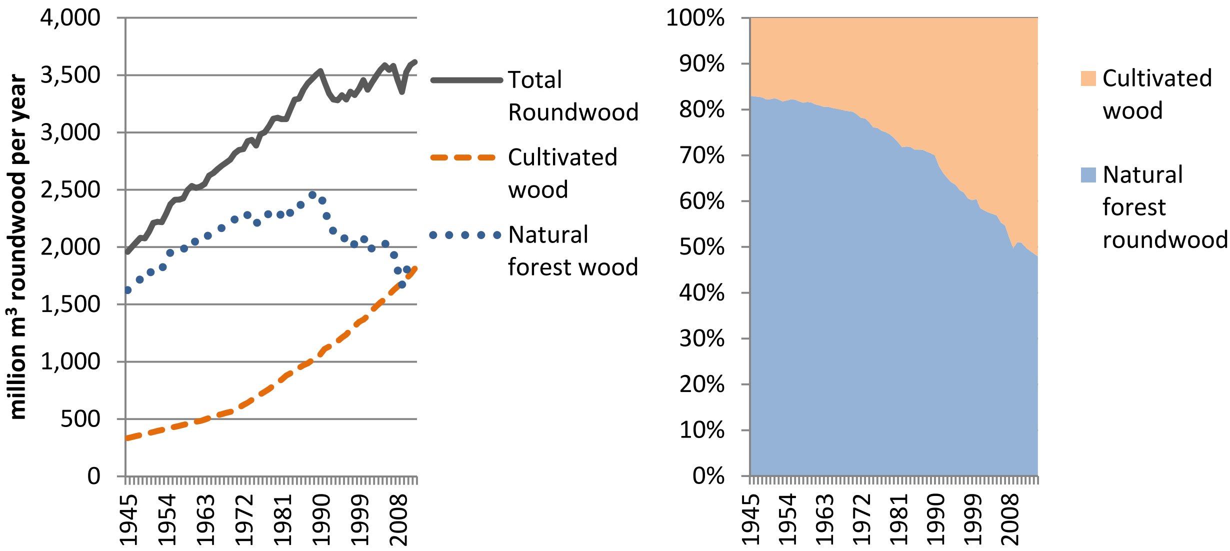

Figure 23. Global wood production 1945-2015 (left graph) and percentage of two major wood types (right graph).[68]

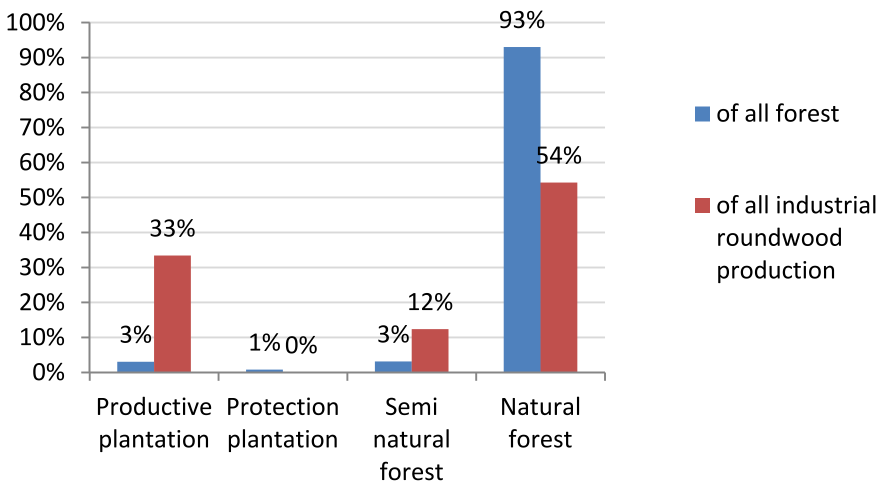

Figure 24. World forest extent and industrial roundwood production in 2012.[69]

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68 Natural forest wood here includes semi-natural forest wood sources. Estimates for cultivated wood is average of high and low plantation scenarios from Chapter 5 and total wood from FAOSTAT (2016).

To conclude, the final part looks particularly at the significance of the changes outlined for the understanding of change (theory) and for recommended responses to change (policy). Chapter 9 will ask; what are the implications of the thesis' findings for understanding transitions in forestry, forest and land use, and resource use theories? Does it verify theories of resource and sustainability management in changing societies? It includes a discussion of the potential for a *plantation conservation benefit* from the expansion of wood cultivation. More broadly, it also asks what can the transition of wood production tell us about other natural resource use systems. It also gives some concluding thoughts on the resilience thinking based model of change outlined here. The final chapter starts with a consideration of future research possibilities and research limitations and then considers how the findings of this thesis might apply to policy relating to wood/forest socio-ecological systems. The chapter concludes with some consideration being given to what it might mean to be acting in these policy settings in a realm of reflective modernity.

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[69] Forest extent data is estimated using data from Forest Resource Assessments of 2005 and 2015 including rates of change (FAO 2006, 2015b). Industrial roundwood production estimates are from (Jürgensen, Kollert, and Lebedys 2014).

9 Understanding transitions in natural resource use systems

> *Most of the long-term growth in wood supply is occurring in countries that developed forest plantations over the last few decades (in Asia, Latin America and Oceania). In spite of some data limitations, it is evident that wood supply (particularly industrial roundwood) is shifting from natural forests to planted forests. This means that pressure on natural forests as a wood source is likely to diminish further in future.* (FAO 2010a, p. 103)

9.1 Assessing the Plantation Conservation Benefit [70]

At a global level there is a clear pattern of wood production moving to increasingly higher yielding wood cultivation forms. At the same time a growing area (of a slowly shrinking global forest estate) is being turned over to forest ecosystem management free of wood production. There can be no doubt that at a global level the world is shifting to a more land sparing approach in relation to wood production and forests. This pattern is reflected in the three case study countries. The idea of a land sparing approach in forestry has been around for some time. As noted earlier, numerous stewardship foresters have recognised the quandary presented by limitations on the capacity of remaining natural forests to meet timber demand, while satisfying increasing demands for forests to be set aside from wood harvest in order protect non-wood values. Many have embraced the solution of using high productivity wood plantations. The idea has a 'logical simplicity' that makes it 'not surprising that this idea has a long lineage' (Pirard, Dal Secco, and Warman 2016, p. 122). An extension of this idea is that setting up plantations will cause wood production in natural forests to be

[70] Section 9.1 draws on the paper 'Do timber plantations contribute to forest conservation?' (Pirard, Dal Secco, and Warman 2016). It is included in full in Appendix A.

reduced. This has recently been labelled the *plantation conservation benefit* (Pirard, Dal Secco, and Warman 2016).

There is an obvious correlation between increased cultivated wood production and growth in the forest conservation estate But drawing causative relationships is problematic and it is difficult to determine the extent to which plantations might actively increase natural forest protection from wood harvest due to economic substitution effects. It can be difficult to determine, for example, the effects of subsidies on the price of both plantation and natural forest-sourced woods, or the extent to which plantations are developed in response to declining natural forest wood supplies. Nor is it clear that policy decisions have been the driving cause of the plantation conservation benefit. In the Australian case, for example, there is not clear evidence that it was always a clear policy intention to deliver a plantation conservation benefit. Other policy intentions can be posited. These include encouraging plantations in order to grow overall wood production (with no intent to increase natural forest conservation), or encouraging plantations in response to anticipated future declines in natural forest wood production, and anticipated mismatches between demand and natural forest supply.

As well as these problems of showing causation, the plantation conservation benefit hypothesis is often analysed in a manner that relies on a number of assumptions. Five assumptions were noted by Pirard, Dal Secco, and Warman (2016). The first is that logging forests causes a loss of conservation values. There is considerable evidence for this, despite substantial effort to achieve sustainable forest management, as noted in this thesis. A second assumption that is often implicit in analyses conducted on this question is that all natural forests have equal conservation benefit. As noted, it is difficult enough to determine the economic effects of a particular set of plantations on natural forests as a whole, let alone comparing the values of different forests. The use of this assumption was a limitation noted in the analysis of leakage in Australia. Assumption three is that the wood from plantations can substitute wood from natural forests. Wood types from plantations and natural forests are rarely perfect substitutes. However, changes in wood processing technologies are often able to adapt to these imperfect substitutes. This is becoming more so as wood processing shifts more to engineered and reconstituted wood products where differences in timber qualities are less significant. A fourth assumption is that the effects of leakage are known and managed. Trade leakage can undo the conservation benefits of forest protection in one country. The Australian case in Chapter 7 showed that the plantation conservation benefit can occur without leakage but there are contradictory examples from other countries such as Vietnam (Meyfroidt and Lambin 2009). As noted above, taking the globe as a whole indicates a net plantation conservation benefit is taking place, so it can be presumed that the net leakage effects globally are still positive.

The analysis by Pirard, Dal Secco, and Warman (2016) involved a literature review of a corpus of twenty six published research papers. These were found to be of three main types. Those based in descriptive statistics used published data on wood production and forest extents. They showed evidence that supports the view that a plantation conservation benefit is occurring but generally fail to show causation. The second type was based on theoretical modelling using land rents and price effects. These tended to be at either a local or international scale. Their reliance on price effects can limit them to the effects of policy and regulation but they provide insights often missed by descriptive statistics. A further limitation is that the modelling itself relies on extensive use of assumptions and these can significantly shape model outputs. The third category of research papers are econometric models that look in more detail at relationships between elements of the models used above. They try to pinpoint causative relationships between plantation establishment and forest conservation.

Pirard, Dal Secco, and Warman (2016) also considered policy implications, highlighting the limitation of simply increasing plantation wood supply with a view to it having a positive nature conservation outcome. There were two possible negative outcomes for natural forests associated with increased plantation wood. Firstly, there is the possibility of rebound effects (Greening, Greene, and Difiglio 2000) along the lines of the Jevons paradox (Jevons 1865) occurring in relation to wood demand. As the price of wood falls due to increased plantation wood supply, demand grows and pressure *increases* on natural forests for wood. A consideration here is the extent to which plantations act to lower wood price, thus setting up conditions for rebound effects. If plantation wood supply is being developed because higher wood prices make it increasingly viable, this is less likely to produce a rebound effect. Over time, however the pricing of plantation wood may change. For example, it is possible that plantations that were established early continue to be cost ineffective against wood from natural forest wood sources, especially when the latter comes from endowment forests with limited costs beyond access infrastructure and harvest costs. By comparison, plantation establishment requires these costs plus purchase of land, and planting, establishment and maintenance costs. Nevertheless, this is also likely to be an environment where induced innovation acts over time to decrease costs. The other confounding factor in considering possible Jevons paradox effects is that the wood from natural forests and wood from plantations are not nearly so perfect substitutes as coal. This is likely to also limit the potential rebound effects.

A significant challenge to the plantation conservation benefit is the possibility that lowering the value of natural forest land by reducing demand for its wood renders it more prone to being cleared for other land uses. This concern has some limitations however. It assumes land and forests are traded on open markets (most of the world's forests are government owned) and that there are no government regulations to prohibit or regulate forest conversion. Conversely, though, it is also possible that conversion of forest to agricultural land will occur regardless of a regulated market if there are few or no effective policing arrangements.

The other potentially negative outcome of increased plantation wood supplies is that of decreasing the value of forested land. If demand for wood from natural forests decreases and the value of forested land is reduced accordingly, then, it could be subject to greater pressure for conversion to agricultural land. While the corpus studied in this review did not contain specific cases of this the theoretical modelling points to it being a possibility. It may be that the absence of such cases of an increased deforestation effect is the challenges that is posed by trying to demonstrate the effect in practice. But another consideration is the role of land ownership. Such theoretical modelling assumes that land exists in something like a perfect market, as noted. However, around 80 per cent of the world's forests are owned by governments and are not generally freely available for trading in markets. They are subject to government regulation (when well enforced) or, conversely, problems of commons (where regulations are poorly enforced). Even where land exists in markets it is possible that a range of regulatory and social factors will limit the effects of pure market forces acting on it.

In both cases, rebound effects and deforestation effects, a key policy consideration is the combination of policy to support plantation expansion with policy to protect natural forest from wood harvest. In the three national case studies presented here government policy has played a significant role in determining how wood/forest socio-ecological systems have been shaped. They highlight the significant limitations of simply analysing land use patterns through theoretical market analyses alone.

The policy mechanisms displayed in the case studies include protection of forests in conservation reserves, regulatory restrictions on harvesting of timber and reviews and reductions in allowable annual cuts. Importantly, these restrictions can have the effect of reducing wood supply and therefore triggering the same sort of economic processes that a complete exhaustion of endowment or natural forest wood supply will have—induced innovation and investment in wood cultivation causing its comparative advantage to improve. There is a clear synergistic advantage to having in place a combined wood industrial policy and forest management policy to optimise the potential of achieving a plantation conservation benefit.

As noted in Chapter 7 this sort of integrated policy is also critical to reduce or lessen the potential impact of leakage effects. As noted in the case of Australia, there has been a synchronous arrangement of plantation policy increasing the plantation estate and its productivity while increasing the area of natural forests protected from wood harvest and managed for non-wood values.

> *Reductions in wood production arising from the conservation of natural forest in Australia have been more than offset by increased wood production from plantations. As a result, displacement of wood production to other natural forest in Australia or internationally has been minimal, indicating no significant negative leakage. The experience of Australian forest policy therefore confirms the potential of land-sparing, in which large areas of natural forest can be conserved by intensifying wood production from plantations with high wood productivity.* (Warman and Nelson 2016)

This experience is relevant to other nations facing combined pressures to conserve natural forest and develop plantations and other wood supply alternatives. The New Zealand case outlines a similar example, although it seems more likely that the net effect of the transition to a cultivated wood products sector in New Zealand has been a significant net positive leakage as it became a major exporter of cultivated wood.

The above review of the *plantation conservation benefit* raises another interesting possibility—the potential for non-wood values of extensive natural forests other than the biological conservation values to be realised at a greater extent than would be possible in a wood production regime. In particular, there has been much written about the need to consider social forestry in managing forests. At times this also runs up against the interests of wood harvest companies. By shifting wood production to wood cultivation sources might there be better realisation of social forestry outcomes? This seems to be a particular potential in Indonesia, where there are often intense conflicts between social groups with strong traditional connections with forests having access restricted or denied as the forest is utilised for wood production. This, then, raises the possibility of a *plantation social benefit.*

9.2 Technology and induced innovation

In September 2016 the New Zealand Government announced seed funding for research into 3D printing using live tree wood cells. The research is to consider the possibility of being able to lay down tree wood cells with a 3D printer in a set form, and then, by triggering the cells to change to a wooden cell structure, the printed form will turn to wood—leaving a printed wooden object—all, 'without the need for the destructive harvesting of trees' (University of Canterbury 2016). Printing wooden products from cultured tree cells is a logical (if considerable) further evolution in a process of increasingly intensive and technological wood production. It is consistent with a pattern of shifting wood production from timber/lumber wood products to reconstituted wood fibre products and of shifting wood growing from extensive forest management to fibre cultivation. It highlights the ongoing potential for technology and induced innovation to act as a destabiliser to wood/forest socio-ecological systems.

With a growing global population and increasing per capita wealth pushing demand, induced innovation will continue to occur and act on the system. This raises critical questions about what pushes the quest for innovation. A Malthusian perspective would suggest that capacity for innovation is limited (certainly, not to be relied upon) and the growth in demand for wood will lead to overuse of the resource—as has been noted, there is considerable evidence of wood resources being used in non-sustainable patterns. However, if, as Boserup theory suggests, innovation is induced in response to a mismatch between demand and the ability of current systems to meet that demand, technological innovation will likely be induced. Where the systems in question are complex, such as a wood/forest socio-ecological system, there will be multiple parts of the system where innovation can occur, continuously shifting the sustainability equation. In addition, technological change outside the wood/forest socio-ecological system can have impacts on the sustainability equation. For example, increased use of electronic screens to substitute paper as a reading material is having a major effect on wood/forest socio-ecological systems. Yet, this screen technology has not been developed in response to any aspects of the wood/forest socio-ecological system. While Malthusian and Boserup theories are seen as opposing models for how resource use systems operate, in the case of the wood/forest socio-ecological system, considerable evidence exists for both. In addition, there is the possibility that Malthusian analysis acts as a useful feedback mechanism within the system—a critical first cry from the lookout that the system is heading in the wrong direction. But, once this information is relayed to the crew, it is clear that they have capacity to make changes to their course.

This thesis has noted considerable evidence of innovation responding to changes in the supply/demand equation. At a global aggregate level this is seen in declines in per capita wood demand and per unit GDP wood consumption (Figure 25). At a global (aggregate) level improvements in productivity are remarkably consistent in their persistence.

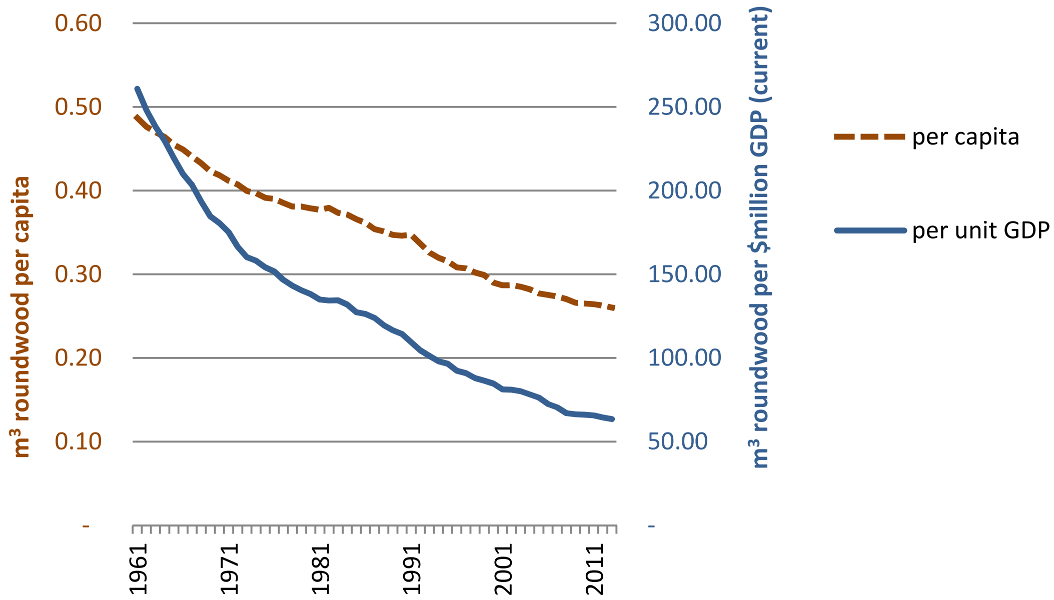

Figure 25. Global roundwood consumption m³ per capita and per $ million dollars GDP. [71]

There is evidence that there have been ongoing improvements in cultivated wood productivity, although they are by no means guaranteed (Powers 1999). It is likely that this will mirror increases in agricultural productivity. What is striking about this form of technological advancement (increases in agricultural productivity) is the extent to which it is historically consistent. This is an

71 Population and GDP data from Worldbank and wood production data from (FAOSTAT 2015) and (World Bank 2015)

expression of technological advancement embedded in collective social enterprise that is distinct from the notion of development of technologies by remarkable individuals (Akrich et al. 2002).

As noted in the previous section (on the plantation conservation benefit) there are considerable concerns about the potential negative effects on land rents leading to increased deforestation and conversion of forest to agricultural land. However, such concerns need to consider the many ways these pressures can be relieved throughout the wood/forest socio-ecological system. In particular, the pressure to raise land prices can induce innovation in productivity—as indicated by Boserup. Growing land cost pressure and wood cost pressure can be addressed by increasing use of land for more plantations, but, it can also be met through three other key routes: increasing productivity of existing plantations, utilising degraded and underutilised cleared lands, or, increasing the productivity of wood utilisation. The same applies to agriculture itself. Reducing agricultural land by converting some of it to plantation does not mean that demand for food automatically requires more land. Such an assessment requires an assumption that all other aspects of the food production system (for example, consumer demand, processing, climate, distribution and storage, agronomic technology, other agricultural input production such as water and fertiliser, trade, biotechnology and genetics, subsidies and regulation) all stay constant. They do not. All these aspects contain possibilities for improving the productivity of food. Therefore they have the capacity to change demand for food from a reduced land area.

It is useful at this point to look a little more at food production because it is increasingly an integral part of wood and food cultivation systems and is likely to provide insights to the future of wood cultivation that the history of stewardship forestry might not. Food production globally in the last several decades has grown significantly without requiring commensurate growth in arable land. Tilman (1999) describes how the world increased food production in the 35 years to 1997 by 200 per cent, with only a 10 per cent increase in land used. Conversely, it did require a 68 per cent increase in irrigated land and 348 per cent increase in nitrogen and phosphorous fertilisers. An analysis of the FAO data below shows a similar story of growth in productivity while land use has grown considerably less (Table 4). These findings indicate the considerable capacity of agricultural social-ecological systems to increase productivity through means other than increasing available land area[72].

Table 4. Changes in productive area and productivity for major global agricultural outputs (FAOSTAT 2015).

Agricultural Product	**Growth in land used 1961-2013**	**Growth in production 1961-2013**	**Average annual growth in productivity 1961-2013**	**Average annual growth in productivity 2004-2013**
Cereal	11%	192%	2.08%	2.19%
Coarse Grain	3%	164%	2.23%	2.83%
Fibre crops	-9%	96%	1.56%	1.74%
Oil crops	148%	664%	2.17%	2.46%
Root crops	18%	85%	0.93%	1.37%
Meat	9%	335%	2.72%	2.50%

Table 4 reveals the possibilities for increased production of crops without increasing land impacts. A similar process is seen in the relationship between meat production and land developed to meadow and pasture, where meat production has grown while land used has been relatively stable. Tilman

[72] This is not to deny that there has still been growth in land area demand for most agricultural products and this is contributing to global land use pressure.

observes that the productivity of crops may be reaching the limits of the 'saturating yield curves' and that it might not be possible for the process to be repeated. However, the results in the table do not indicate this, with productivity increasing for most agricultural products faster in the last ten years than in the overall 52 year period reviewed. Further, in the case of wood production it seems that this sort of saturation is less likely to have been met, given the relative infancy of wood cultivation compared to other agricultural sectors, especially outside the temperate regions.

The relative ability of wood cultivation to deliver large volumes of wood without having a significant impact on global land supply is also visible in the realm of fuelwood. The dramatic shift in fuelwood production to non-forest sources in rural landscapes where trees are grown as integral parts of landscapes, often using the interstitial spaces in the landscape, shows this potential. Taken together the evidence suggests a significant capacity for wood cultivation intensification to meet future wood demand through an intensification/land sparing approach.

By comparison, Fox (2000) observes that certified natural forest wood production is in the order of 0.7 m^3/ha/yr[73] which, he notes, would have taken 4.7 billion hectares of natural forest to supply all the world's wood demand at the time. However, the world has 3.7 billion ha of natural forest in 2015 and 1.3 billion of that is primary forest (FAO 2015b). This highlights the difficulty of delivering wood from land sharing approaches (for example sustainable forest management, ecological forestry, restoration forestry) though this is not to say that there is not capacity for both approaches.

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73 He cites Binkley (1997) for the certified natural forest wood production figure.

As mentioned at the end of Chapter 3, it is an ironic consideration that in modelling the future in relation to policy we could consider technological innovation predictable. Can novelty be predicted? Or is such technical advance the result of a reliable and incremental process of innovation and adaptation? This analysis points to the potential for technological change to be predicted. It shows a trajectory of almost constant change resulting from technological innovation. And, while the specific future of technological innovations might be harder to predict, it seems that technological innovation and, thus, a change in the sustainability equation is highly likely.

Technology has had an important role in the transition of wood production from natural forest extraction to cultivated wood sources. The shift is fundamentally enabled by new technologies of wood cultivation as well as being influenced by changes in wood processing technologies and changes in how wood products are used (which are also technology-related changes). Technological innovation must be taken into account then when considering how resource use socio-ecological systems respond to resource limits. It is an enabler of solutions to limited food, water, land, and wood. Its development can be an induced response to the pressure of necessity born from established patterns of resource use coming up against limits of resources as theorised by Boserup in relation to food production.

9.3 Social systems

The above analysis and its theoretical underpinnings can lead to a view of technology as a fixed and exogenous factor operating on the socio-ecological system—a form of technological determinism. Davison (2004, p. 134) describes these views, or experiences, as, '*technologies as neutral servants* and *technologies as autonomous masters*' (author's italics). However, as Davison notes, there is a third way in which technology is seen as a 'social practice'. Once technology is brought into the social it can become subject to praxis. This has implications for how futures are predicted, how the social actors within the socio-ecological system discursively frame the future, and the myriad choices as to how and when to seek innovation, invest in research and deploy technologies. Innovation, change and technology form part of the social.

9.3.1 Prediction as creation

Wackernagel et al. (2004, p. 273) note four main ways that human societies tend to avoid the population/resource overshoot common to populations of other species—overshoot being a lag between population decline or stabilisation when a limiting resource reaches its limits. First, they note that much resource demand by humans is not required for direct bodily consumption, but rather, indirectly in the creation of goods, giving considerably more time and scope for substitution and innovation. Second, trade acts to dramatically increase the 'catchment' from which resources can be drawn. The third and fourth are both technological, the third being the ability to manage and manipulate ecosystems to dramatically escalate their productivity of wanted resources (as exemplified by aquaculture, agriculture and wood cultivation), and finally there is technology's capacity to develop substitution. The problem of running out of wood to burn for energy to power industrial societies was 'fixed' by substitution with fossil fuel, much as renewable energy sources are now starting to address the issue of limits to fossil fuels.

This does not mean there will always be a technological 'fix' available [74], but within a complex society there are often many possible options for substitution, and while the lack of technology might create a dead-end down one substitution path, many others will still exist. These can range from the more direct such as substituting farmed fish for wild caught fish, or less direct, such as diets shifting from fish to vegetables or new methods of fish distribution or processing reducing waste (and so increasing supply). It does make prediction difficult. Critically, Wackernagel et al. (2004) note that these processes make it misleading to take static descriptions of the balance between resources and humans from which estimates of resource limits can be drawn.

The value in understanding the past (as studied here) is being able to then apply it to the future. A part of this is the articulation of predictions about futures for wood/forest socio-ecological systems. In the early stages of this thesis it was intended to include a chapter that undertook quantitative modelling of future wood supply scenarios. However, reviewing past efforts revealed how challenging this sort of work is and how problematic. For example, Nilsson and Bull (2005) provide a summary of major global wood supply assessments from 1990 to 2000. They show that it was often assumed that, with shrinking fuel wood demand (replaced by fossil fuels and reducing competition with industrial roundwood) and growing plantation supply coming on line, there would be no impending industrial roundwood supply shortages in the first half of the twenty-first century. However, they then conducted their own 'back of envelope' forecast, and this revealed a future mismatch between demand (higher) and supply (lower). Of most importance, they note that at a global level a mismatch

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[74] It is worth noting the work of (Gordon 2016) who argues with some force a somewhat unconventional proposition that the ability of society to develop new growth through technology is not guaranteed, with specific reference to the US case since the Civil War.

between these two must always be reconciled (Earth cannot import wood from off-planet).

As noted in Section 5.2.1 there was a pattern of predicting ever growing demand for wood in the late 1990s and early 2000s that has proved to be inaccurate (see Appendix E for details). It might be that this is the result of predictive methodologies that have failed to take account of changes in technology that cause these (in retrospect) inflated predictions of wood demand. That is, these predictions assumed that population and wealth would grow, thus increasing future demand for wood, whilst changes in wood production technology and wood saving technologies were not adequately considered. This history of forecast failures also raises the question: to what extent do industry bodies, and perhaps government forecasters including the FAO, keen on growth of the sector, tend to talk up the future potential growth?

It seems that part of the problem here is that the process of data collection itself is not just an objective analysis of wood/forest socio-ecological systems. It is embedded within the system itself. This embeddedness can be seen to act in two ways. First, there is an almost infinite number of questions that can be asked of the wood/forest socio-ecological system. But, with limited resources, choices need to be made and these are likely to be influenced by the values, imperatives and aspirations of those who have the resources to make those choices.

A question that comes up in relation to the research question in Chapter 5 is why was this question not answered earlier? Why had no organisation, and in particular the FAO, asked this question about the amount of wood coming from natural forests and cultivated sources? One possibility is that the organisations with the resources to be asking these questions were dominated by stewardship forestry thinking and that the distinction was not of central importance to its main goal of wood production—it was all wood and all within the domain of forestry. It is only in recent years that this distinction has started to become a factor in question construction. Part of the problem, as noted in Chapter 5, is that the distinction between natural forests and forms of cultivated wood is not always clear. In recent years there are emerging indications of efforts to address this question (Batra and Pirard 2015; Carle and Holmgren 2003; Penna 2010), and to better clarify categories within global plantation production (Jürgensen, Kollert, and Lebedys 2014). This emerging trend to ask these questions is perhaps indicative of the institutions of stewardship forestry beginning to grapple with the shift from stewardship forestry to wood cultivation and forest ecosystem management systems.

Secondly, these analyses and findings themselves enter into and act upon the system being studied. '[O]fficial statistics are not just analytical characteristics of social activity, but … enter constitutively into the social universe from which they are taken and counted' (Giddens 1990, p. 42). Such 'authoritative' data are central to state power; indeed, to the constitution of the state. This is also likely to be true for the institutions of stewardship forestry, in that the data collected will reflect hegemonic organisations and act to further consolidate them through a constitutive function. This would be consistent with the problem of 'institutional "gaming"', that Lindenmayer (2016) notes, in which resource stocks and supplies are over-stated for reasons of institutional or organisational advantage. Noting again the change in efforts of international organisations to grapple with wood cultivation as distinct from wood production in extensive forest ecosystems, this further indicates wood/forest socio-ecological system transformative and adaptive responses to change.

9.3.2 Social inertia, resistance and change

A question I have consistently asked through this research project is 'how do societies respond when engaged in a non-sustainable resource use trajectory?'

With limited forests and fixed levels of productivity from natural forest management and an expanding demand for wood arising from growing population and population wealth, it is clear that rates of wood extraction from forests indicate a 'non-sustainable resource use trajectory'. The term *trajectory* is important. The sustainability of current activity is measured by the possibility of it being able to continue at current rates into the future. Sustainability is posited as a quality of the present but is based on the potential of the future. A trajectory of resource use is mapped and it is determined whether the resource use system is or is not sustainable. This is where it gets interesting, because the designation of 'non-sustainable' is also reached by projecting the current situation into the future, yet if key parts of the system are changing, and, further, if there is significant scope for feedback and consequent unpredictable change (for example, as resource exhaustion approaches), then it becomes harder to specify sustainability based on extrapolation of the present.

The shift of wild-sourced wood to wood cultivation is likely to have implications for understanding shifts in other systems of wild caught or collected resources to cultivated or recycled sources, for example; declines in wild fisheries and increasing fish farming; shifts to increased recycling of water, aluminium and paper fibre; and shifts from agricultural land expansion to productivity increases. These are critical processes when it comes to fitting a growing and large global population, with increasing resource demands, into a finite planet. Understanding how these changes unfold, and what inhibits them, is vital. An aspect of this shift is the movement of the extractive activity following a receding resource frontier. When this is occurring it is clearly not a sustainable process—no wild system has endless frontiers—and yet the society that is dependent on it will wish to continue deriving the benefits to be had from this process, thereby leading to the calamity of ongoing pursuit of the frontier. Still, as the viability of the wild source decreases, the socio-ecological system will need to change. These systems will, however, have numerous alternatives, which involve the establishment of systems that cultivate the resource in a managed manner that is usually more intensive and largely capable of rapid renewal. Agriculture is essentially this response for producing food. Wood cultivation is the same for producing wood. To lesser or greater extents such systems can themselves be developed in such a way as to use natural resources as inputs or places to dump outputs in non-sustainable manners. Even so, when cultivation systems are established they become conceptually closer to being self-contained and self-sustaining than those systems acted on frontiers.

In either case, wild-sourced or cultivated, the system is bounded and ultimately must operate within those bounds. The difference is that the shift to a cultivation/recycling system reflects recognition of these bounds. Given the crisis that the end states of the wild-sourced system will generate, the trick is to avoid this crisis by recognising it with sufficient time to make necessary changes. An analogy can be had from a large ship on a trajectory that will bring it onto a large rocky island (Figure 26). There are many points at which the ship can start turning away to avoid the rock. In spite of this, the later it is left the more effort it will take to turn the ship (by analogy, the more disruptive it will be to the socio-ecological system).

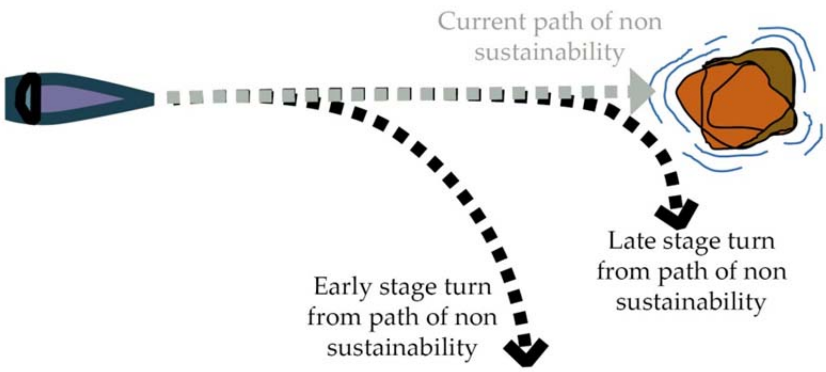

Figure 26. Representation of ship (socio-ecological system) changing direction (transforming) in order to avoid running ashore on a rocky island (catastrophic collapse of system).

Systemic inertia in the socio-ecological system surrounding these resource uses is substantial, as noted in the previous section. It could be likened to the inertia of the ship. There is much in the system that acts to perpetrate its current state (its trajectory). This will include actors within the system acting to maintain the current trajectory (the crew choosing to continue the ship on its course with the rocky island). The tension between demand for non-wood values and the drive to maximise the resource for a single use is a feature of the transformation of the stewardship forestry basin into its subsequent basins (this could be seen as a dispute within the crew and passengers of the ship about the best course of action).

Those wishing to maintain the current course can be comprised of powerful distributional coalitions that have coalesced around the maintenance of a system even when engaged in a non-sustainable resource use trajectory. In the case of the forest resource, this contestation has been touched on in this thesis at a number of points, though the intense political nature of these conflicts has not been dealt with in the main text. Ossified social relations and structures that support a given non-sustainable trajectory can respond slowly to their decreasing tenability in the face of increasingly obvious limits to a certain patterns of resource use. This is a powerful source of inertia to a system. Lucas and Warman (submitted; see Appendix B) have looked particularly at the schizophrenic nature of a resource use in a socio-ecological system that has descended into intense social polarisation over a particular natural resource use conflict (see also Guber 2013; McCright and Dunlap 2011). This can have the effect of stifling effective change to systems at multiple levels.

Professional identity is a component of the formation and maintenance of professions (Sommerlad 2007). The central profession of the stewardship basin, foresters, are likely to form part of a more extensive discourse coalition (Hajer 1993) that will include regional communities, timber companies and unions acting in support of a status quo. Identity, along with ideology and political differences, will act to strengthen these discourse coalitions. They will tend to act together to maintain the system in a state that benefits them and resist change. The Tasmanian case study analysed by Lucas and Warman describes this discourse coalition in some detail. It also describes the formation of an opposing discourse coalition that progressed ideas of system state change particularly in order to advance non-wood value protection in forest ecosystems subject to stewardship forestry. Together, these opposed coalitions acted to form what Lucas and Warman (submitted) describe as 'ruts', 'a set of conditions in which polarising social constructs gain a momentum that perpetuates entrenched discourse coalitions, storylines and values into subsequent issues'. Another way of describing a similar form of social inertia and resistance to change is that described by Costanza et al. (2017) as 'social traps' or 'societal addictions', which describes collective commitments to unsustainable resource use patterns as being analogous to personal addictive behaviour.

As noted above, there is likely to be a shift from being a system that is expansionary to one that is self-contained and self-sustaining (even though 'self-sustaining' might include an ongoing evolution in the relevant processes). This is consistent with the idea of Beck, Bonss, and Lau (2003) that the emergence of reflective modernisation includes a shift into perceiving nature as being internal (or integral) to society. This new perception in which society embraces nature leads to new logics. Society is no longer extracting from, or dumping in, from the 'other', an external nature—such extraction and dumping occurs within. The forest becomes not something outside the society from which to draw resource as needed, but *belongs* within. Questions of how to use and how to value the forest are altered through reflexive modernisation.

When this is understood it might become possible to readdress tensions between discourse coalitions that advocate ongoing resource exploitation and those that advocate maintenance of the natural resource systems for other values. The change to a self-sustaining system needs to occur anyway. It is only a question of how far the system goes before it makes that change, and in what ways. This is a matter of making choices. Political, social and cultural choices that might be heavily contested, are of when and how the change gets made—not if (although that also remains a choice of sorts). The important thing here is there are choices to be made. This is a central act reflexive modernity sees for our time.

The New Zealand examples described in Chapter 8, and from Tasmania in Lucas and Warman (submitted), demonstrate processes of institutional inertia that arise as a resource use socio-ecological system coalesces around a fixed pattern of identities, discourse coalitions, and discourses and storylines. Considering these institutional and discursive elements is important in shaping policy. While it might be considered that policy for forests and wood production systems will automatically arise from logical argument based on facts, there can often be conflicting logics behind different identities, values and ideologies that mitigate this. In Latour's words, it is not enough to focus on 'matters of fact' but attention must also be given to 'matters of concern' (Latour 2004). Further, it is perhaps useful to recognise that these matters of concern, as central factors in the shaping of system development and function, need themselves to be understood as 'facts' of the system.

9.3.3 Sustainability

If the world as it will be is different, what does it mean to be sustainable? The foundation of forestry was sustainability, to establish a socio-ecological system that maintained forests, communities and societies that depended on them, most particularly through a sustainable flow of wood. But what is sustainable when the conditions of the socio-ecological system are in an ongoing process of evolution—evolutions that show no sign stopping?

This analysis of the response of societies to non-sustainable resource use trajectories—in this case wood/forest systems—shows that societies do respond. They must. The logic of the trajectory is simple: non-sustainability dictates the system will have to undergo change. In the case of forests, though, what is important is that there have been multiple ways in which that trajectory and its problems are seen. This leads to contestation around both sustainability and chosen responses to non-sustainable trajectories. This, in turn, demands, not just a solution to the problem, but, given the presence of multiple possible solutions, a contestation over preferred futures and preferred sustainabilities.

Forest management requires considerable reliance on informed guesswork, as investing in forest growth can require at least several years and often decades before the harvest of a wood crop is realised. For example, consider natural forest hardwood management based on rotations of around ninety years. For a forest harvested in 2010 this means the next harvest will possibly be in 2100. Given this, it is vital to consider what effort has gone into understanding the society, technology, economy and culture of the world in 2100, and in particular, how, if at all, a calculation has been made of likely wood demands (and demand for other forest values). Do silvicultural regimes currently in place reflect this? Or do they just reflect an extrapolation of the current circumstances? By logic, wood production and forest management should demand the utmost attention to futures thinking—and yet, ironically, this is a process dominated by a stable equilibrium discourse.

Colander (2005) suggests that sustainability is the attempt to maintain a system in a basin chosen from a range of possible equilibria, while resisting forces that might change it. This is consistent with the development of the basin of stewardship forestry, and its associated institutions acting to generate a chosen sustainability—predictable long term supply of wood. The 'choice' to determine a selected state from the range of possible states and equilibria will, however, be subject to changing social, cultural, economic and political ideals. This means that the constitution of sustainability and its potential achievement will be problematic as long as these ideals change. This demands an approach to sustainability of ongoing flexibility (Davison 2008).

Discussion about technology in relation to sustainability can revolve around technology as solution. The ecomodernist would argue that the '[d]ecoupling of human welfare from environmental impacts will require a sustained commitment to technological progress and the continuing evolution of social, economic, and political institutions alongside those changes' (Asafu-Adjaye et al. 2015, p. 29). Conversely, there are those who argue for caution in applying technology in such a way (Grunwald 2016). The analysis here also suggests that careful consideration should be given to how technology is conceived. Technology in the ecomodernist approach and its counterarguments is conceived as a factor exogenous to the socio-ecological system, something that can be chosen, advocated, applied (or not) to the system to fix problems of sustainability. However, perhaps, '[t]echnologies are constitutive of, not external to, our humanity' (Davison 2008, p. 6) and, by extension, endogenous to socio-ecological system themselves. Either way, exogenous or endogenous, it is clear that technology is likely to be an ongoing disruptor to the sustainability equation.

One final consideration in relation to the pursuit of sustainability can be drawn from the ship analogy described earlier (Figure 26). In that analogy a ship is on a course that is non-sustainable and therefore requires a change of direction. However, as noted earlier, the change in path itself requires choosing a new direction. The draw of sustainability thinking in the past has been to attempt to set a fixed route—a new stable regime. However, given the presence of essentially evolutionary processes in social, natural and technological aspects, it might be that it is impossible to determine what lays ahead for the boat. It is likely that in the future a new rock might emerge on the horizon, and the tussle over how to change direction will continue anew. Thus, achieving sustainability becomes not a search for a fixed state, but a recognition that it is a journey requiring continual adjustment.

9.4 The model of wood/forest socio-ecological systems—final thoughts

The model described fits the evidence at a national level and at a global level over the period of the nineteenth and twentieth centuries but it requires some important caveats. The model outlined here makes it possible to consider each country or region with a distinctive wood/forest socio-ecological system as belonging to one of the three stages outlined. Nevertheless, it is clear that the switch between basins is not a neat and clear moment but a progressive, lengthy and sometimes messy shift over time. This was especially clear in both the Indonesian and the New Zealand analyses where the wood/forest socio-ecological system became more clearly seen as a network of systems (or, perhaps, a network of networks). This is a significant caveat on the use of resilience thinking as a model for change in systems such as those described here for wood and forests.

In Chapter 3 it was asked to what extent the resilience model of socio-ecological systems would apply to understanding change in the wood/forest socio-ecological system, as compared to these systems being considered in the light of change in larger social systems such as societal modernisation or industrialisation. It is clearer now that when the focus of the socio-ecological system is the social (rather than the ecological, as was often used in resilience thinking) then there are powerful panarchic influences that create ongoing disruption to any particular system. On the other hand it is also clear that the social in socio-ecological systems includes processes that do act to create internal equilibria—a 'gravity' that gives the system a basin. These act to give a system resilience in the face of larger panarchic disruptions and pressures. Examples of this described in this thesis include the economic pull of path dependence and sunk costs, the pull of power relationships such those described in Indonesia, and the draw of discourse coalitions and professional institutions. Of course, these systems are also subject to the logic of the givens of particular biophysical conditions—climates, soils, forests, and tree types. So while there are clear limitations to the use of resilience thinking for understanding wood/forest socio-ecological system it also has value. The work in this thesis would support the suggestion earlier on that resilience concepts provide a useful framework for describing and analysing complex sets of interacting phenomena when undertaking multi-disciplinary and cross-disciplinary analysis.

The model of change from Chapter 4 works well to describe the stewardship forestry basin as it emerged in the twentieth century. It works best applied outside its core origins in Europe, because it was in part the rapid spread and uptake of the 'technologies' of forestry, along with other features of modernity (nation state, science, capitalism) developed there. This required both the conditions that enabled the development of stewardship forestry *as well as* the globalising effects of European colonisation to disperse the ideas. In some ways the model works as it is because it is sited at the convergence of societal evolution at the global scale that the twentieth century witnessed. It requires the effects of the change in social values around forests and non-wood values that occurred in this time.

As noted, it is less telling of all situations further back in history and it is confounded by the examples of European countries. Here stewardship forestry developed prior to the ecological consciousness of the late twentieth century and often at a point in the wood exploitation phase where there was no extant natural forest left to be stewarded. Thus they effectively went straight to a wood cultivation basin from forest exploitation in the schema proposed at the start of this thesis. Importantly, then, this meant that the stewardship forestry basin that emerged globally was informed by the silvicultural thinking of this initial development. This means that the stewardship forestry phase was to some extent an attempt to impose the agronomic nature of wood cultivation onto extant forest ecosystems, setting up the crisis of the stewardship forestry basin where wood/forest systems began to grapple with an emerging ecological demand for forest services that was not always (even rarely) possible with a wood production optimisation approach.

Similar processes to those in Europe had occurred in Japan, Java, and China previously. What is significant about the European situation is that its institutions went on to influence the formation of the stewardship forestry basin globally. However, the wood/forest socio-ecological systems of Europe are themselves subject to the same rise of valuation of non-wood values. This means that they are also experiencing the same challenges to the wood/forest nexus of the stewardship forestry basin. In this sense the model can be considered to be valid in its European application—but it does require this historic context.

It is also a limitation that nations are not evenly or rationally spread across the globe, and therefore caution and nuance are needed when applying the model to individual countries. In particular, large countries can contain considerable geographic and historical diversity. Take, for example, the 1980s analysis by Sedjo and Lyon (1983, p. 1015) who predicted the shift of wood production to the 'south', or tropics, in the early twenty-first century. They noted that this process could include 'to a lesser extent' Australia. To some degree this has been borne out. Australia was a minor player taking advantage, in the late twentieth century, of the extensive endowment of temperate primary forest that Sedjo and Lyon noted. But that period also saw the burgeoning of highly productive plantation establishment. In the case of Australia then, the global shift of wood production they describe has to some extent occurred. This can also be seen in Brazil with wood production moving from the Amazonian natural forests to the southern Atlantic plantation region, and the US, where wood production has shifted from the Pacific North West to the South East. All cases reflect a shift from the mining of endowment forests to a cultivated wood focused production.

There are significant challenges in moving the focus of analysis from the nation state to the world system. The temptation to stay with the nation state is huge, because nation states often offer relatively rich datasets in comparison to the world system. Studying nation states also offers the ability to study multiple countries and thus understand phenomena by comparing them, something not available when studying a single world system. But the challenge of Beck, to move beyond the nation state in social analysis, is also supported by this work. The three national systems analysed here have shown the rich interrelationship of each with the world system. Trade in wood products and trade in knowledge have profoundly affected each wood/forest socio-ecological system at the national level. Further, the Indonesian case study points to the role of forestry as a globalised institution that plays a constitutive role in the formation and maintenance of the nation state.

The dramatic rise in social valuation of the environment in response to industrialisation in the twentieth century is historically unique. While the setting aside of forest for non-wood values was something that had occurred in preindustrial societies, the examples are limited, and generally small in scale (sacred forest groves, royal hunting grounds). The extent of the valuing of non-wood and even the non-utilitarian values of forests that emerged in the twentieth century was unprecedented in the extent of the change in how wood/forest systems are valued and used. This becomes critical in considering the transitions from forest exploitation to stewardship forestry to the divergent basins of wood cultivation and forest ecosystem management—for a number of reasons. In cases where the extent of exploitation was near complete it is possible that stewardship forestry emerged at the same time as wood cultivation (Germany, Java, Japan). That is, the need to manage forests for wood does not occur until the exploitation of forests is so advanced that it requires the creation of new 'forests' to provide future wood sources. This is different to the recognition that rates of forest degradation and loss are likely to run into future limitations, and that therefore, stewardship forestry is able to establish institutions to manage still extant forests for sustainable wood supply (such as in the US, Australia, India). New Zealand is likely to have fallen somewhere in between the European situation and that of the colonised countries described. The forests of New Zealand were already depleted when Europeans arrived. This depletion then accelerated. As the institutions of stewardship forestry developed they transposed the ideas of European and colonial stewardship forestry to their forests. Despite that, it appears that it took some time for the understanding of the slow growth and regeneration of the specific forests of New Zealand to be fully realised. In the end, stewardship forestry in New Zealand only managed to preside over the slow exhaustion of indigenous wood production. Australia seems to have been more successful at managing the stewardship forestry phase than New Zealand. In part this is because there were more extensive and productive natural forests to put into the stewardship estate to begin with. The stewardship approach arrived at a different point in the exploitation phase, than it did in New Zealand. In Indonesia, the arrival of stewardship forestry came at a point when the extant natural forests were still largely in place. That these forests were subject to land use patterns consistent with the exploitation phase (deforestation and uncontrolled frontier and commons exploitation) is interesting. It shows that the presence of professional foresters and other ideas of stewardship forestry management are not in themselves enough to fully constitute a wood/forest socio-ecological system in that basin.

10 Wood and forests in a post forestry world

> *Environmental and resource regimes have difficulty responding promptly and appropriately to socio-ecological changes … even when the growing mismatch between prevailing institutions and the changing character of biophysical and socioeconomic systems becomes a matter of common knowledge* (Young 2010, p. 384).

Industrialised tree cultivation to meet a globalised wood fibre demand that utilises biotechnologies and highly mechanised wood processing is a long way from the collection of wood for spears and firewood by gatherer-hunters. During the change from the latter to the former people have moved to modes of relationship to forests that are often contradictory. Simultaneous with a sense of separation, allowing exploitation, is a potent longing for missed connections with nature (and forests particularly) that requires action to protect forests from that very exploitation. The emergence of new states and conditions in response to a multitude of factors shows that there is value in taking this wide ranging look at transitions in wood production.

In each of the identified historical phases humans have generally taken advantage of the available resources, and they have responded when the use of those resources has reached limits. These responses have been multifaceted: rules, laws and taboos and the extension of force to restrict and control use of forests; changes in technology to allow the replacement of wood; and the development of innovations in wood cultivation.

As part of this transition the relative importance of wood in total human endeavour has, in some important senses, diminished over time. The development of alternative material technologies and fuel sources has seen to this. The importance of natural forests as the source of wood started to diminish in the last century—in particular, as wood production has shifted to wood cultivation. Thus, the nexus between forest use and wood sourcing has begun to unravel. This is most strikingly seen in the rise of an increasingly agronomic wood cultivation and a growing focus on a natural forest ecosystem management that is devoid of wood production.

The interpretation developed here is novel in its elucidation of the shift of wood production to geographically distinct spheres of endeavour. This challenges the historical integration of wood production and forest management exemplified by the institutions of 'forestry' with their inherent wood/forest nexus. A shift in wood production from forest systems to agricultural systems and the simultaneous shift in forest usage towards increased care for non-wood values are of vital import in the development of policy and management regimes for forests, agricultural lands and the societies that interact with them.

The preceding research of the four defined basins of the wood/forest socio-ecological system describes each basin's underlying logic that lends it resilience. It also describes the internal contradictions that give rise to crises that can prompt eventual transformation. The case studies have further considered these. The following is a consideration of a number of implications for these changes on future research and for policy recommendations for the wood/forest socio-ecological system. As described in this thesis, individual wood/forest socio-ecological systems will continue to be subject to disruption from panarchy effects and shifts in social values and technologies. Adaptation responses within the stewardship forestry basin that attempt to sustain the nexus of wood production and forests that underpins the basin, and the challenge of attempting to resolve key tensions in the wood/forest socio-ecological system by limiting analysis to the domain of forests alone, will struggle. It is suggested in this final chapter that consideration be given to embracing post–forestry thinking and approaches as mandated by the institutional and geographic divergence of wood production and forest ecosystem management.

10.1 Research limitations and future potential research

Research limitations are often discussed towards the end of a thesis. In this case they have been mentioned within discussions of each of the case studies. More broadly, the approach taken of immersion in multiple methods and disciplines has at times created a complexity that potentially limits findings. In particular, being able to clearly point to causative links can be difficult or impossible. The work, then, relies on a degree of supposition and speculation. This can provide value in speculating on possible causative linkages but these, in turn, will require future work.

Science is often portrayed as the seeker of objectivity. I have tried to apply the greatest possible levels of analytical and logical rigour to this work to support that potential. But as an exercise that has straddled the natural and social sciences it should be noted that this entails a significant limitation. (Giddens 1990, p. 16) notes the peculiarity of social science which 'spirals in and out of the universe of social life, reconstructing both itself and that universe as an integral part of that process'. Unlike the natural science (of forestry, for example) which seeks to grow knowledge on a 'parallel track' to the object of its study, the social science can never truly gain that independence (Giddens 1990). In this sense a wood/forest socio-ecological system will always bind its studier within itself, responding and evolving in response to their findings. Research of the wood/forest socio-ecological system is part of the system. If there is a place of pure objectivity to be found at all, then, it must be in the acknowledging of this.

There are, of course, numerous possible future research questions and potential projects that have emerged from this work. Below is a list of future possible areas of inquiry that directly arose from this research and some highlighted considerations for researchers working in this area to bear in mind.

1) Broadly, the shift in wood processing from natural forests to cultivated sources is a challenge for the notion of sustainable forest management, as well as how to optimally provide for forest and biodiversity conservation, and ecosystem services delivery. This merits considerable further research and policy attention.
2) The work here has also highlighted the importance of research on natural forests and their threats, such as agricultural expansion and climate change, to be attentive to this fundamental shift in wood production. The wood sourcing transition significantly alters the dynamics of the systems and needs to be considered in their study.
3) The findings from the Australian case highlight the potential for coordinating industrial wood policy and forest conservation policy. This points to the need for thoughtful analysis and planning that is unique to each national and wood industry setting in order to make sure that industry policies reinforce rather than negate conservation outcomes. Understanding how this policy coordination occurs, especially in contested arenas, would benefit from more research.
4) The projections in chapter 5 are generated using simple extrapolations as described. There was no supply and demand equations included which might have provided more information on potential futures of wood production. However, the model used was developed in order to test the potential future expression of the historically derived pattern of peaking and declining natural forest wood, and was useful for this purpose. It is an obvious area of potential future work to conduct more detailed modelling including general equilibrium work that specifically considers the

distinction between natural forest sourced wood and cultivated wood sources .

5) The potential for a plantation social benefit deriving from reduced pressure on natural forests is another area of potential future research. It would be of considerable value in seeking to increase the forestry benefits to poor rural communities with strong connections to forest areas.
6) Pirard, Dal Secco, and Warman (2016) speculated on the possibility that plantation wood sources could compete with wood from higher cost sustainable forest management and certified wood production systems rather than less sustainable sources of natural forest wood exploitation. This would constitute a possible perverse, or negative, outcome of plantation expansion. This is an area that would benefit from further research in order to understand if this effect is occurring and if so what policy measures might prevent it from occurring.
7) There have been a number of places here where it has been asserted that increasing demand to deliver non-wood values tends to increase costs of wood production in natural forests. While there are some examples where this seems reasonably likely it is still an important point that has limited empirical support. It would be beneficial to undertake further research on this to better understand these effects.
8) Analysing panarchy effects on governance in areas of international trade in wood products, forest conservation and forest governance as well as within federations (for example, the United States, Australia and Malaysia), could be valuable.
9) In the past there have been numerous calls from researchers for the FAO in particular to undertake data collection that specifically distinguishes natural forests and cultivated wood sources (Clark 2001; Pandey and Ball 1998; Varmola et al. 2005; Warman 2014). The FAO have made some

progress in this area in recent years. That the trend of peaked natural forest wood uncovered here had not been considered in such detail earlier highlights the shortcomings of not collecting this data in the past.

10) The insights of Chapter 8 (on New Zealand) would be further strengthened by undertaking the same research in another country, such as Australia, so that comparisons could draw out more robust insights and findings. For a qualitative approach another avenue to conducting this sort of exercise would be to limit the corpus to president, or editors' annual addresses. In the New Zealand journal these appear to be a particularly potent summary of the dominant discourses of the institution of forestry at the time. Together, such an analysis of the evolution of political discourse in forestry across, say, Indonesia, Australia and New Zealand might better inform the validity of the model at a global level.

11) It is also possible that the deepening of social polarisation around the future of natural forest log extraction, a politicisation dramatically heightened by intense environmental non-government organisation activity, has fuelled further investment in lobbying by industry. This would potentially compound the rent seeking distortions to timber industry economics. As a key factor in the unfolding of wood production and forest management, rent seeking should be a fruitful area of further research. Further examination of the interplay between rent seeking and related social and political phenomena could also yield useful insights.

12) It was anticipated that some analysis of national data sets of cultivated wood production and other related factors such as planted forest area, forest area, GDP, might provide further insight into the model of change from Chapter 4. The limited data available on planted forest wood production would require some effort to generate a dataset of a consistent

quality (particularly with time series data). This remains an area of future work.

13) There are also significant problems in comparing national datasets when seeking to understand the transition processes, as various nations, particularly larger nations, contain very diverse conditions. For this reason it might be useful to conduct some research into these processes as they occur within some of the larger nation states (for example Brazil, US, China and Australia). Such work might also involve breaking larger nations into subregions in order to better refine larger global analysis.

14) Stewardship forestry approaches have been significant in the development of institutional arrangements for forest management and wood production. However, it seems unlikely that the stewardship approach in natural forests has had a significant effect on the production of much of the world's wood. For the most part wood extraction has been an opportunistic activity based on accessing forests that, for whatever reason, have large standing volumes that can be used for immediate wood harvest. Increasingly, a growing volume of wood is being produced from tree crops of relatively short rotations of 5-30 years. Large volumes of endowment wood have been taken from forests with little or no origin from silvicultural interventions in the past. In addition, growing volumes of wood are coming from newer short rotation intensive tree cultivation. It is possible then that relatively little of the world's wood will ever come from natural forests managed by long histories of stewardship management. It might be useful to consider how a review or research paper could be written that considered the possibility of this failure of the stewardship forestry model to effectively manage the natural, or endowment, forests.

15) The discussion in Chapter 9 of technology and land use highlights the interconnected nature of considerations of future food, wood fibre and

biomass production. There is a tendency for experts in one or other of these three areas of land use and biological primary production to conduct analyses related to one or other of these, with the remainder being a limited on non consideration. There is clearly value in conducting integrated analysis.

10.2 Policy implications

As land and resource pressure gathers pace, so the need to optimise land use will increase. The process of change described here for forestry suggests that this is most likely to be achieved through increased land use specialisation. This then becomes a strong attractor operating to draw wood production and forest use systems into the new divergent wood cultivation and forest ecosystem management basins of attraction. These divergent basins will allow increased opportunity to utilise extensive natural forests for non-wood values. Changes in forestry institutions will continue, then, including shifts in patterns of professional education, identity, employment and organisation.

As noted in Chapter 5, where demand from natural forests is reduced as a result of shifts in wood production to cultivated sources there is increased scope for managing those forests for non-wood values, especially where wood harvest makes this more difficult. It is important to note that this raises significant challenges for forest owners, and especially governments, to find ways to fund this non-wood producing forest's management.

It was suggested in Chapter 7 that a number of changing factors in Indonesia and in forestry could provide opportunities for a more enduring local participation in forest management. These include strengthening democratic institutions, a shift to forms of governance built on systems thinking, and the declining role for natural forests in wood production as plantations replace supplies. This last factor noted for Indonesia, the transition in wood production that is central to this thesis, is a significant policy implication. The shifts in wood sourcing will change pressures on extant natural forests, and, like the potential for conservation benefits noted more widely in this thesis, they will also provide an opportunity for increased social benefits from forests where these conflict with wood production.

10.2.1 Stewardship forestry

Does the stewardship forestry model work in natural forests or is it simply controlled exploitation of endowment forests? It appears that much of the wood production in these areas has been due to the exploitation of primary forests or successive cuts for lower value species in less accessible areas. This reflects a managed extraction of endowment forests, rather than a perpetually sustainable forest management. The earliest wood extraction often occurred in parallel with land clearing. This was followed by a period in which wood exploitation moved beyond the land clearing frontier and took on the character of selective logging for high value species, and high grading[75] (Hyde 2012, p. 179). Subsequently, forests were logged with new silvicultural techniques, for example using clearfell and fire to increase regeneration of preferred wood species, often with the consequence of ecological simplification (Lunney 1987). Each stage can involve the timber industry returning and adopting to smaller and lower grades of log (Hyde 2012, p. 211).

Of the case study countries, Australia comes closest to displaying a sustainability from stewardship forestry applied to natural forests, with a consistent supply of natural forest wood (at least until the start of the Regional Forest Agreement

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[75] Exploitative removal of the highest grades of timber from a forest.

period that commenced in the later 1990s; see Figure 8). This suggests a form of extensive natural forest management that maintained wood productivity on a sustainable basis. Yet, there is evidence that it still contained a progressive degradation of forests, particularly through diminution of forest diversity and ecological maturity (see, for example, Bekessy et al. 2009; Lindenmayer, Laurance, and Franklin 2012; Lunney 1987).

As noted in Chapter 10, the experiences of Indonesia, New Zealand and Australia all point to supporting the idea that stewardship forestry has acted as a form of control or brake on the exploitation of endowment forests, but has generally been unable to deliver its goal of real sustainability. That is, the forests have continued to be utilised in a forest exploitation manner, albeit one that is much more controlled and slower than might have otherwise occurred. In addition, the stewardship forestry basin had to deal with the emergence of ecological consciousness and an ever increasing demand for non-wood values in forests during this period.

It seems feasible that in the case of the eucalypt forests of Australia and the pine forests of the northern hemisphere some form of ongoing forest management with a sustainable output of 'fibre' was possible, but likely involving some change in forest age class and structure over time. Yet, these changes run contrary to the expectations of an ecologically conscious populace. This significantly limits the capacity to optimally manage a forest for wood or fibre production alone. Even in European countries with relatively long histories of stewardship forestry there is evidence of a slow shift to a greater differentiation of forest between non-wood value forest ecosystem management and production forests (BMU 2007; Meyerhoff, Angeli, and Hartje 2012).

The language of multiple-use in itself is revealing of underlying assumptions, values and the politics of stewardship forestry basin. The term multiple-use was developed to reflect an adaptive response by foresters to the increasing non-wood demands from forests they were managing. It is also likely that development of these terms was in response to political pressure to restrict wood harvest from public forests in particular. It is a critical limitation of the language as deployed in stewardship forestry political discourse that the logic that changing the tenure from production forest to protected forest equates to a shift of multiple uses to a single use—the 'lock-it-up' of forest (for example Bengston, Xu, and Fan 2001; Rasker and Hackman 1996). The terms themselves are of poor correlation with the stated intents behind them. This becomes especially apparent when the alternative to multiple-use forestry is often implied as a single use of conservation. However, multiple uses can be aligned to the more recent conceptualisation of ecosystem services. In the case of forests these can include recreation, non-timber products, wilderness, biodiversity, climate and hydrology. Thus, forest management for ecosystem services without wood production could still be considered multiple-use forest. That it is not says more about the centrality of wood production in forest management in the stewardship forestry basin than about the number of 'uses' for which any particular forest may be managed.

Given the above it seems that the evidence does not support the case that stewardship forestry has been successful in delivering its stated aspirations of long term sustainability. As noted, it is likely that this might have been achievable but for three significant factors. Firstly, the changing demand for non-wood values from natural forests in particular has not allowed a settled or agreed optimal state of forest to exist—the 'goal posts' have been consistently shifting. Secondly, increasing demand to achieve sustainability has made wood production more costly by lowering the acceptable production capacity of forests and at the same time making alternative cultivated wood sources more viable and competitive. Thirdly, changes in technology have also acted to change the sustainability equation.

The wood products sector has had to deal with a relatively unique quality among many economic endeavours: it has a particularly long production cycle for its wood (for example, Binkley 2003; Hyde 2012). This provides a range of challenges for associated industries, such as difficult risk management challenges, difficulties in attracting investment due to the very long lag between investment and returns, and the challenges of foreseeing the future circumstances of the markets into which future wood products will sell. The forest industry has strong incentive to take advantage of standing stocks that exist now rather than engage in the risks of investing in future wood sources. This could partly explain why there has been such a widespread failure to implement successful stewardship forestry in natural forests.

This project proceeds from the insight that there is ongoing change in the use of forests—that the reality of forest thinking and use is best understood in terms of evolution rather than equilibrium. The evolutionary quality of wood production and forest management is a standout feature of its broad sweep history. Yet, paradoxically, the temporally extensive nature of forests, given the long timeframes of forest and wood growth, and the seeming inertia in patterns of use, has grounded the institutions of forestry in notions of stability and equilibrium. Unthreading these two countervailing views will constitute a central task to the future of wood/forest socio-ecological systems. As Kant (2000) notes, this fundamental gap between the practice and culture of forest managers and approaches of stable biology and equilibrium economics, are fundamentally at odds with the highly directional and evolutionary nature of the socio-technological-biological evolution of forests, wood and the people who interact with them. This emerged as a pivotal tension examined in this thesis.

This tension between stability and change is mirrored in the tensions between the emerging possibility of transformation and the established resilience and adaptation efforts in stewardship forestry. Conservatism arising from the long term nature of stewardship forestry (Glück 1987), institutional 'stickiness', or inertia, from the large public organisations and related distributional coalitions (Munck af Rosenschöld, Rozema, and Frye-Levine 2014; Pierson 2000b), and adherence to established belief systems, all act as attractors contributing to a certain resilience for the stewardship forestry basin. The tension between the resilience generated by these institutional attractors and system stressors is evident, for example, in Rist and Moen's (2013) account, as they grapple with the dilemma of resolving the conflict between optimising efficiency in wood production and building resilience in forest ecosystems. Nonetheless, they limit the scope of a potential solution by restricting their search for it within the realm of what can be achieved within forests (and forestry). Given the potential for wood and fibre cultivation outside of forests such restrictions on solutions limit them to adaptation responses only—the potential for transformative change is greatly limited. Likewise, Lane and McDonald (2002, pp. 193-4) repeat a much quoted rationale for the exceptionality of stewardship forestry: this is the 'problematic character of this … slow growing natural resource'. Much thinking has gone into how to address this problem—nevertheless, that it still gets considered when extensive wood plantations exist, is suggestive of institutional myopia and resistance to transformation. By comparison, Leslie (2005) hints at, and Paquette and Messier (2009) and Sedjo and Botkin (1997) clearly point to, the emergence of a transformational solution to this problem, wherein wood production becomes the focus of intensive wood cultivation outside of extensive forest ecosystems.

The changes noted in this thesis around technology and resource use efficiency have contributed to the decline in total jobs in forestry globally. Lebedys and Li (2014) reported that employment in the global forestry subsector (that is, not including the wood and paper processing sectors) had declined from 4.4 million to 3.5 million from 1990 to 2011. Wood processing sectors had also declined, though not as steeply. Understanding the role of innovation in ongoing job shedding in forestry is important. The relative role of forestry in the economy of many individual countries has declined, just as it has globally. In Indonesia the forest sector contributed 1.17 per cent to GDP in 2000 and 0.63 per cent in 2013, despite some growth in the total wood products sector in real terms over this period. This is reflected in and consistent with global trends over the same period. Jürgensen, Kollert, and Lebedys (2014) showed a decline in global GDP contribution by forestry from over 1.2 per cent in 2000 to 0.9 per cent in 2011. This was replicated across all the regions of the world. It continued a similar pattern identified in the previous ten years (1990-2000). Particularly when combined with relatively stagnant global demand for wood products, these trends should alert policy makers seeking to utilise forestry as a source of employment (especially in rural communities) with considerable caution. If worker productivity in wood production systems continues to increase in line with well entrenched trends in primary industry and manufacturing sectors, then wood production is unlikely to deliver employment growth.

The development of the multiple-use concept in forestry (Rist and Moen 2013) and changes in forester education (Ferguson 2012) are also examples of awareness of changes in the state of the basin and attempts to address this through adaptation. This adaptability is also seen in the development of retention forestry and ecological forestry techniques. These are designed to allow wood extraction while acknowledging a shift in focus to regenerating forests for their biodiversity and ecological values, rather than simply wood production efficiency (see, for example, Clark et al. 2009; Franklin, Mitchell, and Palik 2007; Gustafsson et al. 2012; Lindenmayer, Franklin, and Fischer 2006). Another rationale for pursuing retention forestry is to maintain the income from wood extraction both in order to pay for extensive forest management and also to give value to the retention of forest when other land uses are an option. There has been considerable research and trialling of ecosystem service payments as a way of deriving income from forests for non-wood values, particularly as public goods (Millennium Ecosystem Assessment 2005). However, a broadscale uptake has still been limited (Daily et al. 2009; Milder, Scherr, and Bracer 2010). In this context, wood extraction might continue to attract interest as a viable source of income to help pay for management. However, where strict environmental regulations are in place, wood production is still likely to struggle to pay the costs of managing a forest (Oliver and Mesznik 2006).

Conversely however, the work of Roessiger, Griess, and Knoke (2011) found that in Germany 'near natural' harvest regimes of selective logging and species diversity could provide an economical optimal choice for risk adverse small forest owners. While a number of countries have extensive forest holdings by small private owners where such processes might apply, globally this is the exception rather than the rule. In addition, Zhang (2001) notes that there is considerable pressure from high transaction costs[76] in the wood industry that predispose the industry to large corporate ownership. In this context, the balance of social political and economic factors would seem to favour market pressures towards intensive cultivated tree development over small private ownership. Nonetheless, Kant (2000) cautions against any fixed or optimal regime for forest

[76] See section 2.6 for details of transaction costs.

management as this varies with the changing socio-economic dimensions, and 'the conventional view of the superiority of private or state regimes over community regimes has been challenged by a rich body of empirical evidence from around the world' (Kant 2000, p. 287).

From the above it can be seen that there are still questions around whether the stewardship forestry basin has more scope for adaptation or must be transformed. Many detailed inquiries, and a sizable institutional effort, signify commitment to adaptation as a response to the emerging contradictions. Still, there are limits to adaptation and its attempt to maintain 'the function [and] structural identity … of that system' (Nelson, Adger, and Brown 2007, p. 397). This will include the point at which the alignment of ideals and technology that define core basin characteristics becomes changed to the extent that maintenance of the basin becomes untenable. At this point transformation becomes the logical and possibly inevitable change process, and further adaptation can become an increasingly futile resistance to transformation, rather than resilience. Failure to maintain cognisance of the mutability of ideals and how they underpin a basin can lead to myopic efforts at adaptation and failure to address the possibility that the basin itself is no longer an ideal state to be maintained.

Understanding this process of system change will allow improvements in policy. In particular, it will allow recognition that these changes can be used to develop policy that incorporates allowance for likely paths of change, ideally before they reach crisis points (Young 2010). It should also result in policy that better manages confrontation between change in state variables and inertia within systems, in the form, for example, of distributional coalitions and institutional resistance. The analysis presented here is intended to represent a widely applicable model for the explanation of change in socio-ecological systems surrounding wood production and forest use.

Taken together, the above factors suggest that as wood production and forest ecosystem management transform into new domains, the central institutions will have to alter. For stewardship forestry this suggests that its institutions, including that of the role of 'forester', will decline along with the method of wood production it 'owns'–the broad scale stewardship of natural and semi-natural forests. As new basins emerge natural resource managers might increasingly take the forest ecosystem management role while agricultural land managers and agronomists take on the cultivation of wood crops. These, then, challenge ongoing attempts at adaptive responses to the internal contradictions of the stewardship forestry basin. At some point the logic of transformation becomes more compelling. It is suggested here that policy makers would do well to consider this approach.

10.2.2 Wood cultivation

It is empirically clear that a shift in wood production from natural forest exploitation to cultivated wood sources is occurring. What is important is to understand why it happens—in order to understand how we consider forest management and forest conservation. A key driver for the establishment of wood cultivation is a mix of upward pressure on wood demand and the reduction or degrading of natural forests to the extent that they can no longer meet demand for wood (regional, national or international).

While the economic logic for the shift to wood cultivation is compelling, it needs to be recognised that there are real and significant challenges in enlarging wood cultivation. The increasing role of cultivated wood in roundwood production includes real threats to biodiversity conservation, especially where conversion of natural forest is involved. In spite of that, the return of trees to landscapes, and associated biodiversity and ecosystem benefits, can also represent significant opportunities. To address these, advice to cease conversion (for example, Elias et al. 2012) must be heeded, as well as making use of the opportunities for existing and new cultivated wood plantings to deliver a range of ecosystem services, especially where they are established on previously degraded, abandoned and barren landscapes (Bauhus, van der Meer, and Kanninen 2010). In addition to these ecological impacts there are significant social effects resulting from the rapid landscape changes that wood cultivation entails, especially when coming from industrial plantation. Recent analysis from Chile (Andersson et al. 2016), Indonesia (Pirard, Petit, and Baral 2017), and China (D'Amato et al. 2017) highlight a mix of opportunities and problems associated with recent large scale development of industrial plantations. Notably, all three papers recommend that companies undertaking industrial plantations have the capacity to mitigate these effects through appropriate engagement (including coordination with government) with local communities. That is, with suitable management practices the social benefits of plantations can be increased while negative impacts are mitigated.

Societies that develop needs and demands from intact forests other than wood may also act to limit wood taking. This has the same effect of pushing demand to new supplies elsewhere, including the establishment of wood cultivation. In the Australian, New Zealand and Indonesian cases there has been considerable government effort to establish cultivated wood sources as awareness of limits to natural forests has arisen. In an extreme case noted in Chapter 4, Japan has, in the second half of the twentieth century, adopted a process of both protecting its remaining natural forests and establishing cultivated trees. It has managed this largely by not utilising their wood. Instead they have been meeting demand through imports from natural forests in Southeast Asia (Dauvergne 1997). This raises again the importance of coordinated governmental responses to both protect forests but also to provide productive wood cultivation sources.

Another policy consideration in relation to wood production is future wood demand. Interpreting the future from history is vexed. Simmons (2008, p. xiv) prologues his *Global Environmental History* saying of prognostication, he is 'a bit sceptical of the view the environmental history has a great deal to tell us about the future'. However, it is clear that increasing development of wood cultivation within agricultural domains, such as wood plantations, agroforestry systems and utilisation of non-wood tree crops for their wood—coconut, rubber and palm oil—and shifts in wood processing technologies will continue to modify demand and supply for wood. The same could be said for future wood supply/demand predictions. As noted in Chapter 5, past predictions can be wrong, even systematically so. The extrapolation of the past to the future is difficult. In considering the potential for global biomass production for energy, Hoogwijk et al. (2003, p. 119) identified six crucial factors in considering future availability. They fit well for the related question of future for wood production (its constituent cellulose being a major source of the energy in biomass). These are:

> *(1) The future demand for food, determined by the population growth and the future diet; (2) The type of food production systems that can be adopted world-wide over the next 50 years; (3) Productivity of forest and energy crops; (4) The (increased) use of bio-materials; (5) Availability of degraded land; (6) Competing land use types, e.g. surplus agricultural land used for reforestation.*

There are a number of considerations in relation to future wood supply predictions. Three noted here are future biofuel demand, increasing CO_2 fertilisation and land availability.

An major factor in predicting future wood demand will be the role that biofuels play in global energy demand. Recent outlooks for industrial roundwood for wood and paper products suggest that there will be sufficient supply to meet demand and keep prices low. Nevertheless, while traditional levels of fuelwood seem to have peaked and are showing signs of starting to decline, there is an unknown factor in terms of future biofuel demand. Fuels derived from wooden cellulose are currently more expensive than those derived from sugars. Notwithstanding that, the costs are declining and could reach a point where they are commercially viable and start to compete with wood and paper product demand for roundwood (Kirilenko and Sedjo 2007).

This picture of a range of contradictory pressures on forests and wood demand in some ways explains how so much uncertainty about forest use policy can arise. As well as a range of shifting and diverse values and expectations from forests and wood existing, advocates for these conflicting values in turn have a range of plausible mechanisms to draw upon in support of a given perspective. In addition, the complexity of these processes and the uniqueness of the singular current evolutionary world system provides just one sample, from which an impartial researcher might try to make sense of what is happening, why, and, critically when dealing with a system or network of systems that is continuing to evolve into a novel future state, what decisions about policy and management need to be made for this future.

There is evidence suggesting increasing CO_2 levels will impact on plant productivity over the next century (for example Kirilenko and Sedjo 2007; Leakey et al. 2009; Taub 2010). A meta-analysis of 15 papers reporting on long term FACE (Free-Air CO_2 Enrichment)—in field fumigation of crops and natural vegetation with CO_2 summarised findings showing that increased CO_2 will stimulate net primary production over the long term along with increased nitrogen efficiency and reduced water demand (Leakey et al. 2009). The evidence in relation to trees and in particular forests is ambiguous, particularly due to experiment limitations in controlling all factors (Kirilenko and Sedjo 2007, p. 19698). However, despite experimental uncertainty about projections, there has been historical work to show that global forest productivity has increased during the second half of the twentieth century. This has been mainly attributed to warmer climate and consequent increase in the growing season (Kirilenko and Sedjo 2007). Recent analysis using long term, whole ecosystem measurements has found strong evidence to support the CO_2 fertilisation effect in the temperate and boreal forests of North America (Keenan et al. 2013).

A key to the transition to cultivated wood production will be the availability of land and water. Past estimates have suggested that there are significant opportunities for expansion, although not without challenges (Nilsson and Schopfhauser 1995). This points to the scale of possible lands available for increased wood cultivation without competing directly with agricultural production. Increasing competition for land resulting from globalisation, population increase and increasing prosperity (Lambin and Meyfroidt 2011) will further incentivise wood cultivation in more concentrated forms. Here then, it is useful to recognise that the shift to cellulose fibre production rather than timber production also opens up future possibilities for fibre cultivation from sources other than wood, such as through grass crops—including sugar-cane, sorghum and maize (Weijde et al. 2013) and microbial sources (Keshk 2014).

10.2.3 Forest ecosystem management

All this points to significant possible conservation gains coming from the transition. There remain fundamental questions about the causative relationships between forest conservation measures and changes in wood sourcing. For example, it is possible that increased reservation and logging bans have forced wood sourcing to tree cultivation, which would signal a conservation gain. But it also possible that reservation of forests and logging bans have only occurred once the commercial value of accessing remaining natural forests for wood has been exhausted, in which case the forests were arguably no longer under threat. It is also possible that conservation gains achieved in one jurisdiction lead to displacement of the logging to other natural forests, simply shifting the impacts from one place to another, and making no net gain.

Concern about leakage is a valid response to proposed actions to protect and conserve forest. At the extreme this leads to observations such as '[l]ogging bans for instance usually transfer harvest pressure onto neighbouring areas … and so achieve nothing at the global level' (Fenning and Gershenzon 2002, p. 295). Nevertheless, as noted in the chapter on land use for Australia and the leakage analysis, there is considerable scope for forest protection to occur in alignment with new plantation establishment. The observation above also ignores the induced innovation in wood use efficiency that can offset reduced wood supply and, indeed, the role of restricting wood supply through forest protection in inducing this efficiency. When engaged with a non-sustainable wood use trajectory this is important, because this policy option will induce the same innovation drive that hitting the limits of available wood from natural forests would have—but allows the retention of natural forests. In addition, as noted in Chapter 6 this synergistic policy alignment of forest conservation and wood cultivation policy can allow governments to take forest conservation actions unilaterally with net positive conservation outcomes.

The emergence of distinct realms of wood production and forest use is not necessarily a move against holistic or integrative approaches to land use. While wood production might become more focused geographically, its emergence into agricultural and other heavily modified landscapes will require new thinking about how wood production integrates within these landscapes. There is a need for landscape rather than forest thinking. Likewise, forest ecosystem management is increasingly less focused on wood extraction and more focused on delivering non-wood values. This will present separate challenges and require new solutions to successfully integrate these functions into its society and economics, in particular, finding ways for society to pay for the management of those values when the forests are not producing readily marketable wood products. While these challenges are considerable, the evidence suggests strong forces are pushing transformation of wood/forest socio-ecological system to these new basins. Wood production is emerging from the woods (forests), as suggested in the title. This in turn provides an opportunity to reimagine new equilibria and states for the world's forest ecosystem and wood production systems.

10.3 Reflexivity and imagining

> *We are abroad in a world which is thoroughly constituted through reflexively applied knowledge, but where at the same time we can never be sure that any given element of that knowledge will not be revised* (Giddens 1990, p. 39).

In the introduction I noted my personal history with plantations and how that might have influenced my choice of thesis topic and the many choices made during this research project. Beck would have it that such reflexivity is part of the zeitgeist of the modern era, a reflexivity born by the emergent properties of the problems, and choices, now found *within* an all-embracing society. Beck says that the reflexive modernisation society must confront itself. The problem is not out there, but rather within. The challenge, Beck says, becomes one of answering the question; 'how do we wish to live?' (Beck 1992, p. 119). This is pertinent when we respond to the way we do things when we know that it is unlikely to be sustainable, though we have much vested in this way. There is much uncertainty, resulting from a daunting complexity, not least due to the presence of humans in the system. The determination of what is right, or wrong, is dependent on contexts that are dynamic and fickle. Maybe, then, it is a matter of making a choice: of asking, 'how *do we wish* to live?', rather than striving to understand the answer to 'how *should* we live?'

Srnicek and Williams (2015) write in *Inventing the Future* that the future of social systems is determined in good measure by the imaginings of those who have gone before. They use the example of the relatively marginal group of economists in the middle of the twentieth century who set about pushing a then heterodox economic liberalism (thinkers such as Hayek and Friedman). By the end of the twentieth century these ideas would form the basis of a newly globally dominant hegemonic neoliberal order. Srnicek and Williams argue that this was not preordained but rather the result of a successful imagining of a future, and communication of that imagining, by these economists. For forestry this leads to the question; what future is to be imagined? And what has been imagined?

In deciding the future of wood/forest socio-ecological systems the foresters and forest metricians have long imagined growing wood supply while reconciling increasing demand for non-wood values. Countervailing this is the imagining of conservation ecologists for extensive growth of the conservation estate (IntAct 2017; Nature Needs Half 2017), and ambitious 'rewilding' initiatives (Fraser 2009). As has been noted, these imaginings are very much contested. This thesis contributes to this contestation and posits a way forward. The title of this section referred to a post-forestry world, suggesting a world without forestry. But, as long are there are forests, and as long as we get wood from them, will there not always be forestry? Is a transformed forestry still *forestry*?

I use the term *post-forestry* to highlight the difference from the forestry that developed with a wood/forest nexus at its heart, and what now follows—and can follow. This is my contribution to an imagining. This imagining is supported by the processes examined in this thesis. If, as this thesis suggests, stewardship forestry is in the process of transforming into divergent spheres of agricultural style wood cultivation and forest ecosystem management, does the logic of the centrality of *forest* in *forestry* hold? This analysis would suggest not. In that, then, *forestry* ceases to exist. We move to a post-forestry condition in wood and forest socio-ecological systems. The wood/forest nexus is undone. Wood production comes out of the 'woods'.

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Appendices

Appendix A. Do timber plantations contribute to forest conservation?

Do timber plantations contribute to forest conservation?

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Abstract

For some time there has been a proposition in forestry and nature conservation disciplines that timber plantations can potentially support natural forest conservation outcomes when wood logged in extensive natural forests is substituted by wood production from smaller areas of intensive timber plantations. Here, we have called this the *plantation conservation benefit*. We review evidence from the literature of this intuitively appealing proposition, both empirical and theoretical, and add emphasis on methods (theoretical modelling, econometrics and descriptive statistics) in order to explicitly address causative mechanisms and potential negative or positive feedback processes. This understanding is critical to developing effective policy. We find a convergence of conclusions of reduced degradation of natural forests associated with the expansion of timber plantations, but also potential increased deforestation due to either lower market value of natural forests in the absence of logging, or displacement effects. Yet, a main limitation of studies is the lack of consideration of the role of policies and institutions beyond market drivers, especially in econometric studies. We conclude on the need for integrated policy approaches applied simultaneously to both natural forests and plantations to maximize the potential benefit.

Keywords:
Timber plantations, Forest conservation, Forest transition theory, Wood production, Forest plantations

1.0 *Introduction*

Globally, deforestation and forest degradation continue to happen at a large scale, with wood extraction a significant cause (Dudley et al., 2014). This has major implications for biodiversity, ecosystem services and local communities and economies— solutions are critically sought.

This paper takes a global look at the role that highly productive timber plantations could play in addressing these problems. We review the hypothesis that natural forest degradation can be reduced by substituting wood extraction from natural forests with wood cultivated in timber plantations,[1] what we have called the *plantation conservation benefit*. It will try to answer the question: 'Is the

[1] We use the term 'timber plantations' to refer to trees planted for the purpose of wood production, including pulpwood plantations and other fast-wood plantations producing biomass for energy. Here it is intended to capture the full range of scales from vertically-integrated industrial plantations to smallholder plantings of trees outside of forests. These would align with the categories 'productive plantation' and 'trees outside forests' referred to in Carle and Holmgren (2008)

substitution of wood from timber plantations good for forest conservation?' This question has a global scope, which means not only that it could apply to any geographical area in the world, but also that plantation development and forest conservation can be related while taking place at different locations.

Given the logical simplicity of the plantation conservation benefit hypothesis it is not surprising that this idea has a long lineage. Foresters of the early twentieth century were recognizing the potential for high productivity plantations to alleviate pressure on natural forests in order that other non-wood values could be advanced (Bennett, 2010). Sedjo has advocated the idea for many decades (see Sedjo and Botkin, 1997; Sedjo and Lyon, 1983) as has Leslie (2005), a leading international forester. In more recent decades the hypothesis has been indirectly expressed through national forest policies where policy makers have become aware of the limitations of their natural forests to satisfy wood needs and meet other values at the same time. They have seen supporting plantation expansion as a way to provide opportunities to reduce pressure on natural forests (Bull et al., 2006).

The development of the plantation conservation benefit hypothesis has in part been supported by the very obvious expansion of the global plantation estate. Wood volumes coming from these sources have been growing over the last few decades (Brown, 2000; FAO, 2010). Jürgensen et al., (2014) found that, conservatively, 33% of the world's industrial roundwood was produced in plantations in 2012. The combination of an expanding global plantation estate and ongoing improvements in productivity to the existing estate point to future plantation wood supplies two to four times higher than current levels by the middle of this century.[2]

Here, we undertake the first exhaustive review of the published evidence on this topic in order to draw lessons for more comprehensive studies on the issue as well as to synthesize results available at this point.

2.0 *Theoretical background*

The dramatic growth in plantation wood sources along with concern about the wellbeing of the world's natural forests has led to the development of a simple proposition that if wood can be produced from plantations than natural forests can be relieved of degradation pressure from logging. This substitution, physical but also economic, allows the plantation conservation benefit to accrue to the natural forests. In this section we challenge the foundations of this hypothesis and point to some of its key assumptions that tend to remain implicit.

Before proceeding with the enquiry, we note that the plantation conservation benefit hypothesis shares conceptual space with land sparing/sharing arguments, that respectively refer to (i) enhanced agricultural productivity per hectare to limit the size of the total area under cultivation and hence pressure on natural ecosystems, and (ii) agriculture undertaken in possibly less productive ways but integrated with the provision of ecosystem services across the landscape such as in agroforestry systems (Fischer et al., 2011; Phalan et al., 2011). Conceptually the plantation conservation benefit is an example of land sparing, and some authors note the similar patterns between efficiency drivers in agriculture and forestry (Victor and Ausubel, 2000).

2 See Jürgensen et al. (2014) for a review of recent forecasts of future plantation wood production.

2.1 *The causality trap: lessons from the forest transition theory*

The basis of the argument can be misleading and self-fulfilling when one looks for empirical evidence. The observation of the concomitant establishment of plantation estates with lower degrees of natural forest degradation or deforestation may look like a convincing observation that backs the argument. Yet, the correlation itself is not evidence of a causal–effect relationship, and statistics must be interpreted with caution.

Indeed, another theory that has been demonstrated empirically in many regions and over centuries explains the transition from high forest cover countries to subsequent stages of increasing and decreasing rates of deforestation until plantations and semi- natural forests develop to fill the gap (Mather, 1992). In other words, this "forest transition theory" is based on the identification of a pattern that provides plantations the historical role to take over natural forests (for both wood production and environmental services) once deforestation has reached an unsustainable level. This forest transition can follow various paths, and some have insisted on the difference between a transition due to economic development and one due to the scarcity of forest resources (Rudel et al., 2005). Whichever path is followed is not the point here, rather we focus on the fact that plantation establishment may actually take on the role of a "gap-filler" in response to a series of stages that contribute to the decline of natural forests as a source of wood products.

If this theory is to be accepted, and once again it is backed by evidence in a number of countries that have already gone through all stages such as Europe or North America, then it has substantial implications for the argument. Indeed, having plantations filling a gap once resources have been depleted to a significant extent, or having plantations anticipating this scarcity and substituting actively for the traditional source of supply, are two very different stories. In other words, the argument that plantations might support forest conservation holds in the second case (active role) but maybe not in the first case (passive role). One could thus ask the question: how can models and empirical studies tell the difference?

A first observation is that for plantations to have an active role, their development has to be part of a conducive and purposeful policy framework. Indeed, in the other case where they have a passive role, they develop in reaction to market signals as wood scarcity provides incentives with increasing prices.[3] We are interested in their potential active role, as its analysis and associated recommendations will support the design of suitable policies in order to tackle the pressing issue of degradation and deforestation. This is the time for proactive policies to make a difference as we do not have the luxury to wait for markets to do so. A second observation is that it is theoretically possible to determine if plantations have started to develop before the situation would require production from alternative sources to natural forests. For instance, their production costs would be higher than those for natural forests when these costs are calculated by removing all subsidies or taxes that are intended to promote plantations over natural forests. Yet in practice it might be difficult to tell which subsidies or taxes serve this purpose or others, for instance energy subsidies.

A third observation is: a passive role for plantations is not equivalent to no role at all. Indeed, even if they do not trigger forest conservation on purpose and only result from an increased scarcity of natural forests with economically feasible

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[3] It must be noted that scarcity can be hidden by a specific policy context that removes expected market signals, as with the case of the pulp and paper sector in Indonesia where pulpwood plantations have developed more slowly than expected because of perverse incentives and the capacity of the main groups to influence policies and to guarantee their renewed access to shrinking resources (Pirard and Irland, 2007).

wood production, they could still be viewed as preventing a near-to-absolute depletion of natural forests. In other words, they would still play a role and have plantation conservation benefits.

2.2 *The argument relies on key assumptions*

There are a number of underlying assumptions to the development of a plantation conservation benefit hypothesis. Firstly, it is assumed that natural forest logging is causing forest degradation. There is considerable evidence that wood extraction from natural forests contributes to forest degradation, especially in the tropics (Putz et al., 2012). This evidence of degradation is also supported by patterns of wood extraction from natural forests which have tended to exhibit non sustainable patterns (Shearman et al., 2012; Warman, 2014). There are other significant threats to the world's forests such as deforestation for agriculture (Gibbs et al., 2010) and poaching of wildlife (Robinson and Bodmer, 1999), although there are often strong interconnections between logging and these other threatening processes, particularly the impact of logging roads on these causes (Laurance et al., 2009). While there is strong evidence to support this assumption, sustainable forest management (SFM) is intended to manage forests for wood production without causing forest degradation. However, while implementation of SFM at a national policy level has made some progress, it is still limited in reach, especially in the tropics and developing world (FAO, 2015). In addition, where it is applied its effectiveness remains contentious (for example see Lindenmayer and Laurance, 2012) and its application can have the effect of limiting the potential supply of wood from natural forests (the impact of protecting Spotted Owl in Pacific North West of the United States is a dramatic example, Murray and Wear, 1998).

A second assumption that is often implicit in these analyses is treatment of all natural forests as if they have equal conservation value. While this assumption can be workable when the option of comparing small areas of highly productive plantation established on land already cleared of forest is considered, it becomes problematic when the plantations themselves are established or managed in such a way that they have negative impacts on natural forest conservation values—in the most extreme case when they are established through conversion of healthy natural forest. While the negative impacts on biodiversity resulting from conversion can be obvious (Bremer and Farley, 2010), the net benefit at a larger scale could still be positive if the new plantations' productivity is of such a magnitude that it offsets the losses against reduced logging impacts across a larger area of natural forest. Estimating net cost/benefit outcomes of such trade-offs is especially complex when impacts on different natural forest and forest values are weighed up.

A third assumption is that wood from plantations is an effective substitute for wood from natural forests. The qualities of wood vary considerably between species and even within the same species across growing conditions and because of individual tree genetics and so wood types in plantations and natural forests are rarely perfect or near perfect substitutes. However, ongoing evolutions and capacity for adaptation of new processing technologies along the value chain in response to changing wood supplies (e.g. McKeever, 1997; Meil et al., 2007) including a shift to engineered and reconstituted wood products, makes the distinction between species and between natural forests and plantations less relevant.

A fourth assumption is that negative impacts created by the displacement of activities to other countries do not offset the positive domestic impacts on conservation. The case of Vietnam is interesting with the implementation of an ambitious program to establish five million hectares of plantations relying on small- holders and at the same time a moratorium on production from natural forests. Yet it was demonstrated that successes recorded within the boundaries of the country were less obvious when displacement effects were accounted for (Meyfroidt and Lambin, 2009). Indeed, more forest degradation and/or conversion took place in other countries in the region, e.g. Cambodia, in order to fill the supply gap created by policies in Vietnam, although the responsibility of the plantation expansion is only partial according to this same study. Other studies have found leakage of forest harvest can occur when logging is limited in natural forests (Meyfroidt et al., 2010; Murray et al., 2004). So this process of leakage must be clearly understood and accounted for when analyzing the plantation conservation benefit hypothesis. Other- wise, the negative impacts are ignored and the benefit of the active role of plantations is not validated.

A fifth assumption is that mature plantations will be used as a priority whenever available in order to save threatened natural forests. Unfortunately this is not necessarily the case. The political economy of forest management will not always act towards such obvious solutions, for example in the 2000s hundreds of thousands of hectares of standing industrial plantations remained untapped in the Indonesian provinces of Kalimantan while there was continued conversion of natural forests in Sumatra to supply pulp mills (Pirard and Cossalter, 2006).

3.0 Methods and results

3.1 Corpus and article classification

Our analysis is based primarily on a literature review, then extended to a discussion with regards to the limitations of existing studies and recommendations for both policies and future research. Our objective has been to include all relevant literature using Web of Science, Scopus and Google Scholar databases and search engines with the following keywords: “plantations”; “planted forests”; “forest degradation”; “forest conservation”; “degradation”; “pressure”; “deforestation”. Generally-speaking articles adopt a social science perspective with economics and policies as the main entry points; and the ecological component is limited to the productivity aspects.

Table 1: Distribution of the reviewed documents based on type of method and scale of application.

Method	**Scale**		
	Local	National	Global
Discussion			Sargent (1992) Victor and Ausubel (2000) Cossalter and Pye-Smith (2003) Binkley (2005) Paquette and Messier (2009) Friedman (2005)
Descriptive statistics		Clapp (2001) Binkley et al. (2005)	Sedjo and Botkin (1997) Sedjo (1999) Waggener (2001) Tomberlin and Buongiorno (2001) Sedjo (2001) Bowyer et al. (2005) Ince (2010) Warman (2014)
Theoretical models	Köhlin and Parks (2001) Linde-Rahr (2003) Jumbe and Angelsen (2011)	Hamilton (1997)	Von Amsberg (1998) Sohngen et al. (1997) Sohngen et al. (1999) Sembres et al. (2011) Heilmayr (2014)
Econometric models	Köhlin and Parks (2001) Linde-Rahr (2003) Jumbe and Angelsen (2011) Ainembabazi and Angelsen (2014)		Sembres et al. (2011) Heilmayr (2014)

We proceeded with a screening of the abstracts to identify eligible articles, namely, those addressing productive timber plantations specifically. We excluded oil palm and rubber plantations as they deal with different products and markets, hence lack relevance for the plantation conservation benefit hypothesis. We also excluded studies that focus on conversion of natural forests in the plantation establishment process, as our analysis is about the substitution effect between sources of timber supply and indirect effects.

Twenty six highly relevant studies were eventually reviewed that either specifically engaged the topic of the relationship between shifting wood production and forest conservation or provided specific empirical analysis that spoke to the topic in their findings. They were subsequently sorted according to the type of analysis and the scale they were applied to (Table 1). Indeed, this classification leads to an identification of results patterns. It is also a way to strengthen our conclusions as it helps to identify the most robust results, as well as the more limited methods. Lastly, this classification enables the identification of the main gaps in the literature with resulting recommendations for future assessments.

Consequently, four main categories of studies were considered: discussion papers, theoretical models, econometrics, and descriptive statistics. The "discussion papers" are general and tend to remain relatively superficial without empirical evidence, and were thus only used to feed the theoretical background section. Our approach differs from a meta-analysis as no statistics are provided based on the corpus, but we pay more attention to the methodological differences between studies in order to explain differing results.

3.2 *Descriptive statistics: plantations are taking over*

Descriptive statistics reflect on and organize data in order to describe phenomena and conduct ex post analysis to see if patterns in data fit expectations of the theory. Their main limitation is their inability to infer causative relationships as they do not consider alternative situations (or counterfactual scenarios) to assess impacts; they can only indirectly point to the possibility of the substitution effect that underpins the plantation conservation benefit. What they do point to are trends in wood production over time and parallel changes in removal of wood from natural forests from production and the increasing share of supply from plantations. But they do not say much about the role played by the 'forest transition theory' in such a substitution, and in turn whether plantations had an active or passive role in the process (see Section 2.1).

For example, the analysis by Warman (2014) finds that wood production from natural forests peaked in 1989, with subsequent stagnant growth in demand and growing volumes of timber plantations filling the gap between total demand and shrinking natural forest wood supplies. Scenarios for the future are also produced to explore the case further, such as those by Warman for the period 1945–2030, where projections are either based on historical trends or on the design of various scenarios of growth in plantation area associated with the review of outlook studies. Such projections point to a pattern of declining wood production from natural forests, but remain speculative because of many unknown factors such as the capacity of investors to finance the expansion of the plantation estate and/or an increase in the productivity of existing estates, and the evolution of demand.

Productivity is stressed by these descriptive statistics. With about a third of the total global industrial wood demand met with industrial plantations, but only a fraction of all forested areas are under this type of management,[4] the contrast is striking. In part this divergence in productivity reflects changes in how natural forests are valued. Because natural forests provide a greater range of goods or services in addition to provisioning services, and societal demand for these is growing, it is suggested by these authors (e.g. Binkley, 2005) that they will increasingly lose their competitive edge to plantations for wood production.[5]

3.3 *Theoretical modelling: land rents and price effects*

A majority of the references that we find in the literature present theoretical modelling efforts at local and global levels, rather than national scale. They are useful in their capacity to test a number of assumptions with empirical simulations, although this is neither a requirement nor systematic in the reviewed articles. Their interest is also largely in their consideration of counterfactual scenarios as this approach leads to a comparison of a world with or without plantation expansion. The factors behind the impacts on forest conservation have more chances to be elucidated in these circumstances, because the reasons for moving in one or the other direction in terms of impacts must be formulated explicitly as part of the mechanics of the models.

The body of theoretical modelling work is highly heterogeneous. In particular the focus can be on the local scale with a study of households' behaviour with

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[4] It is estimated there are between 50 and 200 million ha of productive plantations depending on the definitions and scope (Del Lungo et al., 2006; Indufor, 2012), out of 4 billion ha of forests worldwide.

[5] For example plantation productivity could be growing at 3 per cent per an annum (Binkley 2003) and Brazilian plantation analysis indicates an average MAI for its eucalypt plantations of 26 m3/y/ha in 1990, 30 m3/y/ha in 2000 and 40 m3/y/ha by 2012 (Gonçalves et al., 2013).

respect to fuelwood collection, or on the global scale with forecasts of demand and supply from various sources and following the logic of general equilibrium analysis. Further distinctions within these broad sub-categories can be made depending on the inclusion of a demand elasticity (how consumers react to lower prices), the capacity of a model to allow for direct land competition between agriculture and forestry, the existence of different forest classes with associated productivity, or the recognition of spatial location of various sources, just to give a few examples. Models that operate at a global scale tend to emphasize price effects and provide insights that can be missed in descriptive statistics.

Crucial here is the spatial economics of the Von Thunen framework (see Nelson, 2002) which considers the role of land rents and impacts of shocks and policy changes on these. This model is deterministic as decisions are assumed to depend on the expected returns of land uses: changes in land rents induce changes in land use. The closer the land to cities and their markets, the more intensive the land use for higher-value purposes and perishable goods, which results in agriculture close to markets, low-intensity forestry far away, and timber plantations in between (the shorter the rotation the closer to markets). Its application to the plantation conservation benefit hypothesis suggests a key role played by the price elasticity of demand. Indeed, when markets exhibit a high demand elasticity, the prices for forest products will be more stable in a period of timber plantation expansion, and the changes in land uses will be of less importance. In other words, with increased overall demand for wood products and hence sustained demand for wood from natural forests, the prices will remain stable as will returns to land for natural forests under production. It implies that forest degradation might continue but forest conversion might be (partially, and in relative terms) avoided.

Related to this observation, studies based on theoretical modelling are potentially problematic as the design of the model can to a large extent determine the outcome. This points to a critical phenomenon that might significantly shape the expected impacts of the expansion of plantations. Indeed, some models do not account for the competition among land uses and hence fail to account for the impact of the establishment of plantations on displacement of the other land uses. This is a key and very tangible aspect to understand the impacts of plantations, as their expansion could displace agricultural activity that in turn leads to the conversion of natural forests. This can occur immediately as plantations are established, but could also occur during later surges in demand for food. This is not always reflected by the models, with misleading results as reduced degradation is shown but the other side of the story is left aside, namely deforestation risk.

Studies at the household level are devoted to wood extraction as a source of forest degradation. The models look at decisions made by households among a previously identified set of sources: no impact is expected to happen beyond this area and trade is not addressed. The models rely on the maximization of the utility of individuals to simulate choices in terms of wood sources, and this utility is calculated based on observable parameters, especially distance and associated requirements in terms of time and overall cost of transportation.

3.4 Econometric modelling: rebound effects and risks of deforestation

Econometric studies are mostly used to test the theoretical models that were presented in the previous section. These econometric studies point to some elements of context and the extent of their influence on the impacts of plantations on forests, e.g. land rents, or the price elasticity of demand. This elasticity, which is a critical element of the analysis, is usually determined through global trade analysis. Models show that positive impacts on the conservation of natural forests are very much dependent on a low elasticity that prevents demand from soaring when markets are supplied with new sources of wood. Otherwise, a rebound effect (Greening et al., 2000) is expected because consumers have a tendency to buy more when prices decline and goods become affordable.

These models also have the benefit of pointing out another consideration of the plantation conservation benefit hypothesis, which is that degradation can lead to deforestation. This aspect is addressed in numerous studies about the processes of deforestation across the tropics (Geist and Lambin, 2001)—notably, the construction of road infrastructures for the management of forest concessions that boost investments in the area. It means in turn that any effort to tackle degradation through logging might also lead to avoided deforestation.

But there is the other side of the coin: when natural forests are not logged for timber production (in a sustainable way), their economic value is lower and they might be threatened for this exact reason, as long as land ownership and government regulations enable changes in land use. Indeed they become more prone to conversion as they are less competitive against agricultural rents. In this respect, a lot seems to depend on whether agricultural rents are high (high risk, negative impacts) or low (low risk and overall positive impacts more likely). Arguably, this varies a lot with the geographical areas. Indeed where agricultural rents are relatively low and natural forests are under little pressure or even expand, such as Europe or North America, reducing logging activities is unlikely to lead to conversion. But in other areas where agriculture expands rapidly in forested areas, usually in tropical zones, this assumption might hold true.

At the household level, for fuelwood extraction, various econometric methods are applied, ranging from binary or multinomial qualitative models to impact evaluation with difference-in-difference. Overall, a lot seems to depend on the characteristics of households – in particular the level of education of the household's head, the livestock endowment, the size of the household or its distance to the various sources of fuelwood – and the characteristics of plantations such as size and location.

All in all, econometric models attempt to capture the causal relationship between plantation establishment and the conservation of natural forests. One of the main advantages of these models is the possible introduction of interactive variables that enable the identification of certain elements of context that condition the plantation conservation benefit. However, several methods, such as instrumentation or the use of Generalized Method of Moments (GMM),6[6] could be envisaged to better treat the potential endogeneity bias caused by reverse causality (Table 2).

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[6] The general idea is to introduce lagged variables as instruments in the equation. This method enables to account for endogeneity caused by simultaneity bias, reversal causality and omitted variables (Arellano and Bond, 1991; Blundell and Bond, 1998).

Table 2. Main results for each article of the sample (except for discussion-type articles).

Reference	Main result
Local	
Ainembabazi and Angelsen (2014)	The introduction of commercial timber plantations has reduced the natural forest production by 15.5% compared to the counterfactual situation
Jumbe and Angelsen (2011)	A one hectare increase in plantations area reduces by 2% the fuel wood collection in customary forests
Linde-Rahr (2003)	Wood from plantations and from natural forests are substitutes: a one unit decrease in the shadow wood price from plantations decreases the share of collection from open access forests by 0.3 units
Köhlin and Parks (2001)	Village woodlots reduce wood extraction from natural forests by 13% Plantations should not be settled too close or too far away from natural forests
National	
Binkley et al. (2005)	United States plantations will be able to respond to the entire increase in timber demand. Demand pressure on natural forest will be halved
Clapp (2001)	Chile plantations captured traditional markets supplied by natural forests but it did not reduce logging in natural forests because of a new external demand
Hamilton (1997)	Indonesia moderate demand increase and high dependence on timber plantations for wood supply will reduce deforestation
Global	
Heilmayr (2014)	Heilmayr (2014) Plantations lead to lower areas of logged natural forests, yet this positive impact is mitigated when the elasticity of demand is high
Warman (2014)	Wood supply from natural forests has peaked and supply from planted forests is growing
Sembres et al. (2011)	Plantations increase deforestation rate in countries with high agricultural rents. They reduce this rate in countries with low agricultural rents
Ince (2010)	Emerging role of plantations in timber production

Reference	Main result
Bowyer et al. (2005)	Emerging role of plantations in timber production
Sedjo (2001)	An innovation shock implies an increase in plantations' establishment that relieves pressure on natural forests
Tomberlin and Buongiorno (2001)	Wood supply from plantations unlikely to be enough to reduce pressure on natural forests by 2010
Waggener (2001)	Removal of natural forests from production and emerging role of timber production from plantations
Sedjo (1999)	An innovation shock implies an increase in plantations' establishment that relieves pressure on natural forests
Sohngen et al. (1997) Sohngen et al. (1999)	More plantations reduce long term price levels by 12% and thus reduce harvest in remote old-growth forests by 15% compared to the baseline scenario
Sedjo and Botkin (1997)	Placing only 5% of the current forest area under intensive plantations would be enough to meet the demand for wood products
Von Amsberg (1998)	With an inelastic demand, the increase in timber supply induced by plantations creates a real drop in timber prices that leads to less degradation of natural forests

4.0 *Discussion*

4.1 *Findings so far: a variety of methods, issues and findings*

It appears that depending on the methods, results may differ and point to complementary or contradictory impacts in terms of forest conservation. Therefore, by placing studies in several categories based on the methodological approaches applied for each of them, we could separate more or less rigorous and reliable studies from a methodological point of view. Indeed about half of the articles included in our corpus are either of a discussion (no specific evidence produced) or descriptive statistics (no modelling of interactions or the factors of change) type, which means that they have limited value in providing new evidence in support of causative relationships. This is important because ignoring these causative relationships significantly affects the relevance of knowledge for policy making. For instance, it is simplistic to consider one fixed demand and one given rate of expansion of tree plantations, and then deduce the area of natural forests that can be spared from degradation and/or conversion. Nevertheless, these studies are useful for underlining trends in productivity and spatial location of the plantation estate.

Theoretical models are powerful tools. First, they can be applied at a global or national level and build on the spatial economy Von Thunen framework, also integrating the issue of global trade that proves critical in an era of globalization with high risks of displacement effects. Second, they are applied to study household strategies and behaviour for fuelwood collection. They show that household characteristics play a significant role for predicting the outcomes of the establishment of tree plantations devoted to energy production in rural areas. The respective locations of the forest and plantation, along with size and species composition, are critical factors that determine their relative access and associated transportation costs, which in turn lead to forest conservation or, on the contrary, to business-as-usual forest degradation. But their limited scope on fuelwood extraction necessarily limits their lessons to a specific, yet very substantial issue in some developing countries.

Insights from econometric models refer to several key determinants of impacts: most importantly the price elasticity of demand and the level of agricultural rents. Indeed, if the demand for wood products is very sensitive to price fluctuations on the markets, then a rebound effect can be expected that could partially or fully offset the positive impacts. This is to be taken seriously, as this rebound effect has been observed for other products historically in line with the conceptualization by Jevons (1865) for the case of coal. The ability for rebound to occur will depend on what is driving the substitution. A rebound effect is most likely if the cost of plantation wood is competitive and pulls prices down.

The issue of agricultural land rents can be understood as follows: when wood products originate from additional timber plantations, the full sustainable production potential of natural forests (maximum sustained yield) might be untapped as demand is satisfied. A perverse effect can occur if agricultural rents are high enough in forested areas and standing natural forests lose part or all of their market value (not accounting for the range of non- market environmental services they still provide), and this in turn leads to their conversion to other land uses. The key caveat on this scenario is that the forested land has to be subject to property rights that do not restrict its use or saleability, however in many cases around the world the forests are owned by governments (up to 80% of the world's forests (White et al., 2006) or are on private land that can be subject to regulatory restrictions on its use (e.g. threatened species legislation or slope protection regulations).

Our review highlighted the importance of careful consideration of the type of impacts on forest conservation. While the focus tends to be on degradation arising from logging, the interconnected processes being reviewed (particularly displacement of activities due to scarcity of land) can also lead to deforestation. Impacts then need to be divided into more or less degradation and deforestation. As a matter of fact, most studies and the terms of the debate lack clarity on this distinction, and many remain ambiguous with respect to the nature of the impacts on forest conservation that they analyse.

4.2 *Policy implications*

Two significant negative outcomes have been identified in relation to the plantation conservation benefit—the rebound effect on wood markets and the alteration of land rents for forests. These have significant implications for policy design. One implication of this is that policies are required to secure positive impacts for forest conservation through the avoidance or mitigation of the rebound effect. In part this can be achieved by placing restriction on natural forest harvest—for example by regulating and enforcing sustainable forest management, sustainable allowable annual cuts or complete bans on natural forest logging. In this scenario policy restrictions on natural forest logging can act in the same way that other biophysical limits to natural forests do by creating a restricted supply and raising wood prices, thus increasing the comparative advantages of plantation wood. The limitation to this approach is that in one country with trade connections this demand can be shifted to forests abroad—at best supporting plantation development there, at worse shifting to alternative natural forest sources.

Similar challenges exist for addressing deforestation resulting from high agricultural rents creating a risk of forest conversion. Regulations and law enforcement are obvious solutions but can be politically difficult to implement, the more so when the effect can be that part of the benefit is lost to deforestation elsewhere in the world. Furthermore, as pressure on forested land increases then policy makers can be tempted to undo regulations such as moratoriums or protected areas. For instance Mascia and Pailler (2010) show the multiplicity of downgrading, downsizing or even degazettement of protected areas worldwide. The market forces can also by themselves lead to low levels of enforcement, as illustrated by the high levels of degradation in conservation areas in Indonesia (Gaveau et al., 2012). Consideration needs to be given to managing users' demand for agricultural or wood products to avoid pressure on conversion-prone areas. In addition, there is a need for plantations to supply wood for the full range of wood demands, including unique timber species so that plantations do not simply replace the demand for low value fibre supplies. When major changes happen such as China phasing out commercial logging in the country's natural forests with about 50 million m3 of lost annual harvests, plantations have to be able to take over, in order to prevent leakage of logging effort to natural forests elsewhere.

In developing policy there is the need to consider the scale at which the policy is being directed and to recognize different processes by which the promise of the plantation conservation benefit might be achieved. Binkley (2005) notes that at a global scale the approach is to achieve significant substitution of plantation wood in order to reduce threats to the world's remaining areas of primary forests in particular. At a national scale he notes that policies can be directed towards an integrated suite of natural forest protection measures and plantation estate establishment. This approach allows individual countries to secure plantation conservation benefits without them coming at the cost of higher dependence on imports of wood products to maintain domestic wood-based industries and the associated jobs. And then he notes the local opportunities for conservation outcomes that can be achieved when plantation estates incorporate best practice features such as riparian forest reestablishment, set-asides of HCVF areas, and sensitive site rehabilitation with natural forest.

The role of subsidies is ambiguous because on the one hand they give plantations an active role in conservation as their establishment can occur before natural forest scarcity reaches a critical level; but on the other hand they can artificially lower prices and hence may have repercussions for rebound in wood demand, lower production costs in remote forests or even for agriculture leading to forest conversion (e.g. energy subsidies). But incentives can take other forms, such as regulatory restrictions on natural forest logging and deforestation, construction of infra- structures in places dedicated to plantations, or distribution of rights on degraded state land for plantation establishment. All of this, of course, requires effective enforcement, but generally- speaking governments should consider an integrated policy approach of both regulating natural forest wood extraction and supporting plantation establishment. These policies could also include alternative ways of deriving value from natural forests, such as tourism or payment for ecosystem services. Australia provides an example of where a degree of plantation conservation benefit can be seen. Overlapping policies of increasing natural forest protection and plantation establishment have been implemented with a mix of policy approaches (Ajani, 2011), including subsidies (Ferguson, 2014). Over the last thirty years Australian wood production has shifted significantly to plantations while increased conservation reserves and other logging restriction on natural forests have been implemented while increasing Australia's overall wood production levels.

Another potential limitation to the plantation conservation benefit model is that if implementation of low impact logging regimes such as SFM and certification act to increase costs, then plantation sourced wood could end up competing with wood from those more sustainable sources, hence shifting remaining natural forest logging to places without those restrictions. Such a process would be consistent with the market processes described with searches for lowest cost wood supplies directing where wood is sourced (especially if substantial certification premiums do not materialize). In such a scenario, plantation wood would be acting to shift wood production to remaining primary forests with high standing volumes or concessions without SFM. In this scenario it becomes critical to develop policy that protects those natural forests with the highest standing volumes (particularly primary forests) from this perverse outcome. Such moves would both support the expansion of plantation and give light footprint logging regimes their only real chance of being viable.

4.3 Future research needs: the way forward

Further improvement in findings should take heed of the limited aspects covered by the research, several methodological weaknesses and problems related to the availability and quality of data used. We noticed that econometric models in this domain face some critical limits because of the endogeneity bias (caused by potential reversed causality) that can hardly be avoided. Here, we think in particular about the theory of the forest transition and especially the forest scarcity path (see Section 2.1). Econometric models should also account for the time lags between the establishment of plantations and their harvest anywhere from several years to several decades later, depending on the sites, species, quality and nature of products.

We also noticed the relative neglect of several important factors, such as market segmentation, public support policies, and leakage/displacement effects. These should be better, and systematically, integrated in the models to strengthen the results. With the intensification of international trade and better connectivity between places of production, processing and consumption, leakage and displacement effects also deserve more consideration in all studies in this field.

Modelling in its various forms, and the primacy of economic aspects and dynamics in many approaches, entail some limitations that relate to policies (see Section 5.3). In many countries government policy and ownership of forests is highly influential in plantation establishment and forest designation. While this tends to be covered better at national levels, it also means that global modelling could tend to overplay the role of markets influences and underplay political and social influences. For example Friedman (2005) notes that ownership of forests makes a difference when natural forests are publicly owned and can be managed by effective governance so that there is considerably more scope for the plantation conservation benefit to occur. But more generally this raises the need to consider the complexity of the social, political and institutional dimensions of wood production and forest conservation. The relatively simple or one dimensional land use change assessment that is represented in discussion of the plantation conservation benefit hypothesis fails to incorporate multiple intersecting and influential processes.

Data issues were also identified especially for running models on a global scale. This would include the need for specific data collection of plantation estate and production data. Such requests have been made before (e.g. Warman, 2014) and the FAO has in part responded with its recent review of international data on plantations (Jürgensen et al., 2014). At this stage a key limitation continues to be the patchy data collection at national levels. In part the difficulties of getting full national datasets will be advanced by consistent application of definitions such as adoption of work such as that of Carle and Holmgren (2008) that effectively captures the spectral nature of forests and non-forest wood sources. In addition to formal data collection the quality of independent spatial data continues to improve as witnessed by emerging initiatives such as Global Forest Watch.

5.0 Conclusion

The limited research to date generally supports the idea that growing supplies of plantation sourced wood can reduce pressure on natural forests for wood extraction. However, there are significant limitations to published results, which we have demonstrated in this article by making distinctions based on methodological approaches with associated strengths and weaknesses. In particular, we pointed to limitations in the identification of all explanatory variables as well as cause–effect relationships.

The literature also points to a number of potential negative outcomes for forest conservation that could arise from plantation wood sources affecting markets in wood and land. One is the potential rebound effect; another is deforestation resulting from the lower market value of non-producing natural forests. In all cases we suggest that policies need an integrated approach utilizing both regulation of natural forest use and plantation support policies to manage and reduce the potential of these negative feedbacks. Land use planning remains critical for plantations to play an active role in conservation in order to accelerate successful forest transitions; otherwise they are likely to play a mere passive role, simply reacting to market signals when over harvest and forest scarcity make them necessary to take over wood supplies.

It is also clear that there are a number of important distinctions that need to be made in analyzing the plantation conservation benefit. These are; considering the relative roles of wood for pulp, biomass and solid wood applications, whether the conservation impact being considered is forest degradation or deforestation, and taking into account the relative conservation values in the forests being considered (including distinctions of primary and secondary forest, the latter referring to natural forests subjected to logging) but also various environmental impacts of plantations depending on their design and integration in the landscape. All of these must also be carefully considered in relation to the scale at which the analysis is conducted—findings at a generalized global scale might not be applicable in all countries or regions and vice versa. Failure to clearly account for each of these considerations in any analysis of the plantation conservation benefit can lead to individual studies that confuse rather than clarify the processes.

Although the general corpus broadly supports the existence of the plantation conservation benefit, opinions diverge on the desirability of working to retain natural forests for timber production—some support strong levels of protection to give priority to environmental services while others contend that well-designed and enforced regulations enable the combination of timber extraction and the provision of most ecosystem services. We do not take position on this issue in this article, but would like to draw the reader's attention to the fact that lowering of demand for natural forest wood can lower natural forest land rents so that they become subject to conversion pressure, mainly in the absence of any regulatory process to prevent this. This leads to consideration of the range of current and emerging ways of bringing value to natural forest lands to support their retention and management, including developing alternative market signals such as ecotourism, payments for ecosystem services, better integration of local communities in the management of adjoining forest areas, as well as sustainable forest management for wood production. The key challenge is that for any of these approaches to work, a reasonable degree of effective regulatory systems, including enforcement, is needed. And yet the problem mainly arises if there is an absence of regulatory capacity (or willingness) to prevent the deforestation in the first place (another possibility is that regulations change over time to adapt to a changing economic context with higher returns from conversion to other land uses and allow deforestation). The wicked problem nature of this dilemma suggests that there is unlikely to be a silver bullet solution or approach to optimizing benefits and reducing negatives to the plantation conservation benefit where regulatory systems are ineffective.

It is likely that approaches designed for addressing complex problems such as adaptive management and tackling underlying reasons for failure in effective regulatory systems are needed to fully realize the potential of the plantation conservation benefit and to avoid its potential negative effects. It still might be possible that there is a demand for slow grown woods with qualities not easily replicated in plantations. These will by their nature need to be managed on very long rotations of several decades to centuries and are unlikely to ever form more than a very limited portion of total roundwood demand—in effect a boutique natural forest harvest sector for long rotation small volume high value log extraction. It is also possible that a greater portion could be satisfied by natural forest production if certification premiums are substantial enough to compensate for much higher production costs—although this remains highly speculative based on experience so far.

The responses that will be made to these challenges, and the evolution of the values that society attributes to natural forests with resulting demands for better natural forest management, will largely determine the extent to which the plantation conservation benefit can be realized. While the broad trends point to an eventual separation of much wood production out of natural forests into plantations (that would be qualified as 'wood cultivation'), issues of wood qualities, regional and national forest types, land demands and varying social demands from forests mean it is unlikely to be a complete transition of neat simplicity. What is clear is that the plantation conservation benefit contains obvious significant opportunities for meeting societal demand for (and benefits of) wood while improving the chance of natural forests being able to deliver other demands for their many unique and valued non timber services.

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(References here have been retained in format as published – hence there are some differences in style to the thesis' main reference list)

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Appendix B. Disrupting polarised discourses: How to get out of the ruts of environmental conflicts

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Abstract

Polarisation in environmental conflicts obstructs decision-making at all scales. The Australian state of Tasmania has a history of intense polarisation around environmental issues. This article reports on a survey of citizens of the capital, Hobart, and a case study of a recent attempt to disrupt polarisation about forestry in Tasmania. A novel conceptualisation of 'ruts' in environmental conflicts is developed. Ruts are a set of conditions in which polarising social constructs gain a momentum that perpetuates entrenched discourse coalitions, storylines and values into subsequent issues. This is reflected in strong overlaps between the polarised discourses on forestry and climate change. After the long-term failure of traditional authorities to resolve conflict over Tasmania's forests, a sub-political process emerged to directly re-negotiate a shared definition of risk. This article analyses processes that can disrupt polarisation, and offers insights for other environmental conflicts, including climate change.

Keywords

Polarisation, forestry, climate change, discourse coalitions, reflexive modernity, Tasmania

1.0 Introduction

'The surface of the earth is soft and impressible by the feet of men; and so with the paths which the mind travels. How worn and dusty, then, must be the highways of the world, how deep the ruts of tradition and conformity!' Henry David Thoreau, 1854 (p. 346).

Polarisation is often implicated in impasses in decision-making and conflict over the use of natural resources (e.g. McCright et al. 2014, Colvin et al. 2015). Political polarisation is widely blamed for impeding action on climate change (e.g. Hart and Nisbet 2011, Unsworth and Fielding 2014, Tvinnereim 2015) and has also been more broadly studied, for example, in water management (Innes and Booher 2003) and forestry (de Koning et al. 2013). Disputes over decisions about the environment are particularly polarising. In the US, polling shows that polarisation between people who identify as Democrat or Republican is greater for environmental issues than for issues of hunger and homelessness, healthcare, race, unemployment, immigration, crime, terrorism, social security, drugs or affordability of energy (Guber 2012). The formation of rigid discourse coalitions can act as a significant impediment to resolving these challenges (Hajer 1993).

Polarisation has been described as an 'overstretched' term in the social sciences (Esteban and Schneider 2008), and in the political sciences there is a flourishing debate about whether polarisation exists (see for example Fiorina and Abrams 2008, Abramowitz and Saunders 2008). Nevertheless, as Mason (2014) points out, these debates are immaterial to a public for whom polarisation is a real and apparent problem. As it is outside the scope of this article to describe the literature on polarisation more fully, we make use of Esteban and Ray's (1994) broad definition of polarisation as a systemic attribute of society in which a small number of groups (rather than individuals) become highly homogenised internally, but increasingly different and opposed to each other externally. Differences between groups can be political, or based on responses to specific issues, but are always socially constructed.

We draw on the theories of Ulrich Beck and Anthony Giddens on risk and reflexive modernisation (Beck 1992, Beck et al. 1994, 2003, Giddens 1990, 1994) to provide a framework to analyse findings from our case study and survey, in order to illuminate its broader socio-political implications. Following Hajer (1993), we use two concepts from discourse analysis to examine the social framing of environmental conflicts. A *storyline* is 'the medium through which actors try to impose their view of reality on others, suggest certain social positions and practices, and criticize alternative social arrangements' (Hajer 1993, p.47). *Discourse coalitions* are groups of people who share storylines, interpretive concepts, and practices that conform to these concepts (Hajer 1993), but may not necessarily share goals, priorities or values (Bulkeley 2000).

In this article we investigate how polarised attitudes formed through disputes over the use of natural resources can affect the social organisation and public understanding of subsequent environmental conflicts. Our study is based in Tasmania, an island state of Australia. We describe how conflict over the use of Tasmania's natural resources formed 'ruts' – comprising of storylines that are used to appeal to certain values and definitions of the environment, and are tied to the social identities of certain groups of people. We describe how these ruts have persisted from the dispute over construction of hydro-electric dams in the 1970s and 80s, into subsequent conflict over forestry. In this conflict, environmentalists argued for the protection of wilderness and old growth forests from logging, while timber interests argued this was necessary for the economic prosperity of the state. The Tasmanian forest peace process (hereafter the peace process) that occurred between 2010 and 2012 was an attempt to disrupt this polarised conflict (see Schirmer et al. 2016 for a chronology of the process). We find evidence in a survey of residents of the Tasmanian capital, Hobart, that the same ruts present in the forestry discourse persist into the climate change discourse. Through a case study of the peace process, we argue that this is a salutary example of a sub-political process that was able, for a time, to overcome entrenched polarisation. We consider how this example offers some lessons for making headway on the climate change debate.

2.0 *Risk society and reflexive modernisation*

Social theorists Ulrich Beck and Anthony Giddens describe the current era of capitalist, industrialised society as 'late modernity'. Both Beck and Giddens see the modernity of industrial societies as different from the pre-industrial world, in that status and power are no longer based on appeals to forces seen as external to society, such as natural order, tradition or god. Instead status and power are dependent on social relations, and appeals to rationality, expertise or trust (Giddens 1990). The loss of nature external to society is intertwined with the loss of traditional authority (Giddens 1994). The success of the modern project, and the resulting human dominance over nature, has led to the replacement of natural hazards by risks, or 'manufactured uncertainties' of society's own making (Beck 1992, Giddens 1994). In the risk society, the production of wealth from natural resources is inherently tied to the social production of risks. These risks can no longer be scientifically measured or rationally calculated, because risk is not an objective reality but a socially constructed response to complex and unknowable possibilities. In Beck's terms, polarised debates over environmental resources are 'risk conflicts' in which different groups compete to define risk (Beck 1992).

Where multiple and diverse claims to knowledge and legitimacy exist, experts no longer have the power to end disputes (Beck et al. 2003). Public perception has become the ultimate court of decision-making, and power lies with whoever sets the frames for the debate to best suit their agenda. The media play a powerful role in generating storylines that define risks in particular ways. Media content tailored specifically to certain social groups increases the likelihood that people will hear their own views reflected back at them (Bennett and Iyengar 2008). Commercial television, for example, has been found to perpetuate dominant worldviews, values and hierarchies, and its audience to mirror these views (Nisbet et al. 2014). Favouring particular media can lead to an 'echo chamber' effect, where views become gradually more extreme and removed from those outside the group. (Jasny et al. 2015). Countries where powerful media outlets are seen as partisan (such as the US, UK, and Australia) are more likely to generate polarisation through the echo-chamber effect, while a 'market-place of ideas' found in a diversified media environment breaks down these polarities (Farstad 2016). Social media can be effective in mobilising public networks to exert political influence (Castells 2004). However, the more politically charged the issue, the more likely social media is to contribute to the development of echo-chambers (Barberá et al 2015).

Overcoming issue polarisation requires players to negotiate risk definition based on an understanding of their interdependence in resolving the issue. Negotiation of risk may involve developing one or more shared storyline, but need not involve mutual agreement on values or identities. Both Beck and Giddens describe the negotiation of risk as occurring through 'reflexive modernisation' (Beck 1992, Beck et al. 1994). Two central themes of reflexive modernisation are relevant to our study. The first is the dissolution, or re-drawing, of social boundaries. Under reflexive modernisation, belonging to specific social groups (such as nationalities, classes or political parties) is no longer pre-given. When boundaries between social groups are understood to be socially constructed they become subject to choice. Thus traditional arbiters of conflict can be replaced by 'cooperative decision making through ad hoc, sub-political negotiations' (Beck et al. 2003 p.28), where sub-politics is described as allowing agents outside established political power systems to 'appear on the stage of social design' (Beck 1994 p.22). A second theme is the re-envisioning of society's relationship with nature. In reflexive modernisation, nature is no longer seen as an unlimited resource external to society. Science, therefore, ceases to be understood as an instrument of social progress that will enable society to demystify, and thus to control nature (Beck et al. 2003). Scientific arguments and 'facts' might be invoked to justify divergent positions on issues such as climate change, forestry, fishing, and mining, but the use of these 'objective' arguments often masks political, social, or ideological motivations (Kahan et al. 2011, Corner 2012). In a reflexive modernity these underlying motivations become unmasked, so that unquantifiable, 'non-rational' values can become part of the conversation.

We draw on this theoretical understanding of late modernity to investigate to what extent Tasmania's peace process enabled the disruption of polarisation, and whether it can be seen as an experiment in reflexive modernisation. We also address the question of how different environmental risk conflicts can become linked, and how lessons from the Tasmanian example can be used in a broader context.

3.0 *The Tasmanian experience*

In this section we draw on two methods and data sets – a social survey of Hobart residents and a case study of the Tasmanian peace process – to analyse how persistent storylines and discourse coalitions have been perpetuated and disrupted in environmental risk conflicts. The survey and case study described are each part of separate research projects by the two authors, investigating social understandings of climate change and forestry respectively. This article uses the two sets of analysis to examine the links between different environmental risk conflicts.

The Hobart Values Survey explored how people's attitudes to climate change interact with their other values and opinions. Participants were a non-probability sample of 522 adults in the greater Hobart region. Because we were interested in modelling the interaction of personal characteristics and their effect on specific opinions, rather than describing a population, a representative sample was not required (Baker et al. 2013). A detailed account of the methods and results of the survey are included in the supplementary materials.

The case study is based on publicly available accounts of the peace process. In late 2012 and early 2013 the upper house of the Tasmanian Parliament held a Select Committee hearing into the Tasmanian Forests Agreement Bill 2012 as part of its deliberations on the draft legislation. This included 12 days of hearings in 2013 and receipt of over 130 submissions. The transcripts of these hearings and the submissions are publicly available documents and a primary data source for this study. Other publicly available documents were also used. Discourse analysis of this corpus was guided by a combination of keyword searches and the authors' prior knowledge of the process.[1] Analysis was conducted in the context of answering two questions: what were the significant conditions that made the process possible; and how did the process impact or disrupt polarised discourse coalitions?

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[1] One author, Warman, worked as policy analyst for the three environmental organisations involved in the peace process in the years 2009-2013.

3.1 *Falling into ruts*

In the 1970s and 80s intense controversy occurred around the creation of hydro-electric dams in wilderness areas in Tasmania. A hegemonic discourse coalition of business, government and technocratic bureaucracy emerged from the controversy (Hay 1991). This *resource development discourse coalition* promoted a storyline emphasising economic growth and 'balanced' use of the state's natural resources. A reactive *conservation discourse coalition* developed around a storyline about the need to defend wilderness and wild nature from excessive exploitation. This coalition was predominantly led by environmental non-government organisations (ENGOs) as well as the embryonic Tasmanian green political party. In the 1980s, the same storylines were adopted by a mix of new and old players in the growing controversy about logging of Tasmanian forests (Gale 2013). The timber industry cultivated bipartisan political support in the debate (Beresford 2015), maintaining a similar hegemonic discourse coalition to that which had developed over dams. We suggest that the players 'fell' into the ruts that had been formed in the debate about dams.

The dams and forestry disputes are linked in that they are conflicts over the protection or development of the island's natural landscapes. It is therefore not surprising that the same ruts run through these conflicts. However, the debate over climate change is quite different. While Tasmania's natural landscapes are threatened by global warming (especially through increased risk of bushfire, flood and coastal inundation, and changes to the marine environment from the southerly extension of warm ocean currents [Grose et al. 2015]), so are the state's communities, industries and economy (in particular key sectors of agriculture and fisheries [ibid.]). In addition, Tasmania's position as a user and supplier of renewable energy in the form of hydro-electricity (from dams supported by the resource development discourse coalition), means that the island state is wellpositioned to benefit from prioritisation of climate change mitigation policies. Australia's short-lived Carbon Tax, for example, generated AUD$70 million profit for state-owned power generator Hydro Tasmania in 2013 (Robins 2013). The logic of economic development (a central storyline for the resource development coalition) would lead us to expect that supporters of the forestry industry would also be likely to express concern about climate change (and support for mitigation) because of this alignment of interests. However, local contexts provide only part of the picture, and especially in the case of climate change, are not sufficient to fully understand the nature of polarisation.

3.2 Evidence for 'ruts' from the forestry conflict affecting polarisation about climate change

Using data from the Hobart Values Survey, we examined whether there were correlations between polarised views on forestry, and polarised views on climate change, and also whether there were shared factors that predicted polarisation for both issues. The survey data showed negative correlations between support for resource extraction industries (mining, forestry and fishing) and concern about climate change (see Table 1). The strongest correlation was between high concern about climate change and disapproval of forestry. People who think that forestry, mining and fisheries are the most important industries for Tasmania's future prosperity are more likely to be unconcerned about climate change. Conversely, people who think that knowledge industries such as IT and communications, and education and training are the most important have the highest level of concern about climate change. While other factors affecting polarisation over climate change must not be discounted, this correlation suggests the conflict over forestry continues to affect people's interpretation of current issues.

Table 1: Spearman's rank-order correlation between concern about climate change and preferred industries. This table shows the correlation between answers to the question 'How concerned, if at all, are you about climate change, sometimes referred to as 'global warming' (likert scale responses from 1-6); and dummy variables (0-1) representing whether or not respondents thought these industries were among the four most important to Tasmania's future prosperity.

Industry	r_s
Metals processing	- 0.08
Tourism	- 0.03
Manufacturing	0.06
Forestry	- 0.25***
Mining	- 0.11**
Fisheries	- 0.12*
Agriculture	0.07
IT and Communications	0.17***
Education and Training	0.14**
Finance	0.00

* $p < .05$; ** $p <.01$; *** $p <.001$ n=484

Given the link between polarisation about forestry and climate change suggested by this evidence, we sought to understand other factors that affect the membership of polarised discourse coalitions around forestry and climate change. We also wanted to find out whether these factors were similar, or different for the two different environmental risk conflicts. Using binary logistic regression we examined whether demographics, media use or personal values

(Schwartz 2003) help to predict the likelihood of being pro-forestry or anti-forestry, or of having very high, or very low levels of concern about climate change. Details of methods and analysis are in the supplementary materials. Results of the two final binary logistic regression models are shown in Table 2.

*Table 2: Binary logistic regression models showing the variables that predict likelihood of belonging to polarised groups. Model 1 compares the pro-forestry group with the anti-forestry group. Model 2 compares the low/no climate change concern and high climate change concern groups.(* p < .05; ** p <.01; *** p <.001)*

	Model 1				**Model 2**			
	Pro-forestry (cf. anti-forestry)				**Low/no climate change concern (cf. high climate change concern)**			
Predictor variable	**B**	**Odds Ratio**	**95% C.I.for OR**		**B**	**Odds Ratio**	**95% C.I.for OR**	
			Lower	Upper			Lower	Upper
Gender: Male (cf. female)	0.41	**1.50**	0.71	3.20	1.34	**4.03****	1.63	9.92
Commercial media use (weekly cf. rarely/never)	0.56	**1.75**	0.80	3.86	0.33	**1.39**	0.54	3.63
Commercial media use (daily cf. rarely/never)	1.68	**5.35****	1.78	16.11	1.37	**3.92***	1.15	13.33
Public media use (weekly cf. rarely/never)	-0.96	**0.38**	0.12	1.19	-0.31	**0.74**	0.18	2.93
Public media use (daily cf. rarely/never)	-1.55	**0.21****	0.08	0.59	-1.47	**.23***	0.06	0.87
Values variables [2]								
Universalism-equality: Concern about equality and justice	0.57	**1.77**	0.46	6.78	-1.34	**0.26***	0.06	0.87
Universalism-nature: Care for nature and environment	-1.65	**0.19****	0.06	0.61	-2.71	**0.07*****	0.02	0.25
Security-order: Concern for national security, protecting social order	1.13	**3.10****	1.40	6.86	1.46	**4.32***	1.38	13.53
Constant	-0.19	0.83			0.20	1.22		

2 Values variables are dichotomous: i.e., value is of greater than average importance cf. less than average importance to the respondent (see supplementary material for more detail on the process of analysis).

Model fit	$\chi 2$ (9, n=197)=41.84***	$\chi 2$ (8, n=357)=64.35***
Nagelkerke R2	0.28	0.36

a

The analysis showed a number of shared factors predicting membership of polarised discourse coalitions around forestry and climate change, as well as some differentiating factors (notably gender: being female did predict concern about climate change, but not about forestry). The strong relationship between the two polarised issues of forestry and climate change is evidenced by almost all of the relationships with the predictor variables (positive or negative coefficients) being in the same direction for both forestry and climate change.[3] Neither age nor level of education was found to be significant in predicting polarisation for either issue. As has been found in other studies on polarisation about climate change (e.g. Hmielowski et al. 2013), use of commercial media predicts lack of climate change concern, and use of public broadcast media predicts high levels of climate change concern. A similar pattern of media use is found in the groups polarised around forestry: respondents who were pro-forestry are more likely to refer to commercial television and radio while those who are anti-forestry are more likely to watch and listen to public broadcasters. This is suggestive of an echo-chamber effect. Public and commercial media tap into divergent storylines about the nature of the problems and values at stake. This is consistent with observations that the commercial media in Tasmania during the long debate over forests formed part of the resource development discourse coalition (Beresford 2015).

3 The exception was universalism-equality, but this was not significant for forestry.

We examined the impact of the whole spectrum of human values variables on belonging to these groups; however, 18 of the 21 values variables did not significantly improve the fit of the model and were excluded. High concern about equality and justice was significant for climate change but not for forestry. Importantly, both high levels of concern for nature and the environment, and high levels of concern for national security and social order are significant in polarisation of forestry and climate change. These variables represent two differing definitions of what is at risk within the environmental conflicts – a loss of nature, versus traditional hierarchies and industries that provide security and social order. The survey shows that in both forestry and climate change, these different definitions of risk are active. Beck and Giddens' linking of the discourses of tradition and nature is borne out by this empirical data. Discourses embracing nature or traditional social order on the point of their collective disappearance are for these writers a nostalgic defence of what once gave our lives boundaries, and had greater power and authority than individual human agency. Trying to defend either nature or traditional social order, both discourse coalitions attempt to protect a particular (and likely a passing) way of life (Giddens 1994). Our findings from the Hobart Values Survey illustrate the depth and persistence of ruts in these polarised discourses about environmental risk conflicts. Importantly, they point to social factors such as values and identity for continuation of the ruts rather than economic factors alone.

3.3 Getting out of the ruts

Forestry is a significant part of the society, culture and economy of Tasmania. Forests cover over 50 per cent of the state (FPA 2012). Tasmania has 0.9 per cent of Australia's land (Geoscience Australia 2016) and 2.1 per cent of its population (ABS 2015), but during the period 2001-2014, on average it produced 22 per cent of Australia's wood production each year (ABARES 2015). It has also been a major source of political controversy in the state. From the late 1980s onward a range of government-led processes sought some settlement of the issue. These were typically bureaucratic and technocratic, the most notable being the Regional Forest Agreement (RFA) process of the late 1990s. The RFA attempted to diffuse the conflict by using a scientific process to determine what areas of forest should be reserved and what areas could be logged. However, from a risk society perspective, in an environment where there were multiple opposing claims to knowledge and legitimacy, the authority of science and government no longer held. As a result the RFA failed to resolve the conflict (Lane 2003, Kirkpatrick 1998). It was in this context that the peace process was conducted between 2010 and 2012. It is considered to have had some success in dealing with long intractable problems between long term adversaries (Schirmer et al. 2016). Critically, it managed to disrupt established ruts. In the following sections we look at what lessons might be drawn from this experience.

3.3.1 Enabling conditions

We identify two sets of conditions that contributed to the emergence of the peace process. The first were processes that contributed to alternative storylines and new styles of sub-political risk negotiation. In the past, Australian ENGO strategies primarily involved attempting to influence government as the arbitrating authority (Dawes 1985). In the run up to the peace process new approaches were emerging. In 2009, the initiative of Our Common Ground, an informal coalition of mainly environmental interests, sought to promote a collegial way forward (Jim Adams, Afternoon Session 15 Jan Select Committee 2013: p. 27). Our Common Ground promoted a new storyline which focused on the cost of the conflict to all parties including the public, a need for new politics and consensual approaches, arguing that '[f]or years, Tasmanians have been forced into old fights as if the world wasn't changing around us' (Tierney 2009).

Our Common Ground acted through 'embedded environmentalism' (Dolšak and Prakash 2016) laying out solutions to the conflict that specifically addressed the demands of both conservationists and timber industry supporters. This was achieved through storylines demanding both better forest protection and ways to address employment and economic issues, primarily by advocating a plantation based timber industry. It also appealed more broadly to the Tasmanian community by speaking of the possibility of 'peace' for the whole Tasmanian community as a viable alternative to the conflict.

Concurrently, the Australian branch of the Forest Stewardship Council (FSC)[4] had been becoming increasingly important in Australian forestry. Under pressure from public opinion, Japanese companies – the largest customers for natural forest woodchips – began to demand FSC certification (Beresford 2015, p.242). While FSC did not play a direct role in the negotiations, it was catalytic in forming social relationships between key players from the polarised discourse coalitions, who might otherwise have only interacted adversarially. Leaders from both sides had been working together through FSC Australia prior to the peace process and thus had experience of a model of non-governmental deliberative governance over forest management (Jim Adams, Sean Cadman and Natalie Reynolds in 5 Feb Select Committee 2013). State-run forestry operations in Tasmania did not have this certification, but an agreement with ENGOs was likely to improve their chances (Bob Annells in Morning Session 12 Feb Select Committee 2013).

[4] The FSC is an international non-government forestry certification body. Its governance structure ensures equal input from three 'chambers' – environmental, social and economic. This was designed to prevent any one sector from becoming dominant and in doing so forces all three sectors to work consensually (Cadman 2009).

The second group of conditions contributing to the emergence of the peace process changed the operating conditions and power relationships within the conflict. These were: changed market conditions for the timber industry; and changes in the political environment with the formation of novel Labor/Greens coalitions at both state and federal level. From around 2008 a number of timber market changes confronted forestry in Tasmania. The global financial crisis had a large impact on global wood markets (Beresford 2015). Tasmania's timber industry, particularly its largest private forestry company, Gunns Limited, started to struggle to find markets for its wood. Several industry representatives referred to a 'perfect storm' in industry conditions in the hearings (e.g. Bob Annells, Afternoon Session 17 Jan 2013. p.31, Select Committee 2013). In this environment, ENGOs were increasingly successful in turning international customers away from Tasmanian wood. In 2010, Gunns made a decision to exit the natural forest sector, its CEO proclaiming the environment movement had 'won' (Beresford 2015).

In addition to these changes in markets there were changes in government. A Tasmanian state government election in 2010 resulted in a new ruling coalition between the Greens and the Labor party.[5] Labor had been a traditional supporter of the timber industry, while the Greens were strong advocates of changing forestry practices, and in many forests, ceasing production altogether. In September 2010, an Australian federal Labor Government was elected that also required support from the federal Greens party to pass legislation. At both levels of government this was a rather uncommon alliance in governing coalitions, between a pro-industry workers' party and a pro-conservation party. This set the

[5] Also of significance was the potential role of Our Common Ground in supporting the Greens' vote and influencing the state election outcome of 2010 (Douglas 2010) while at the same time communicating broadly the possibility of a negotiated peace.

scene for government to take a more consultative role – because to try to adjudicate on this matter would have exposed both Labor/Greens coalitions on one of their most awkward policy differences. Indeed, the need to avoid the traditional adjudication role of government might also explain why both governments clearly stated that they would only accept an agreed position as policy if agreement was reached by the parties to the negotiation – otherwise the government was not seeking to change the *status quo*.

3.3.2 The Peace Process' impact on polarised risk conflict

In the storylines of the conflict, analogies of war had been commonplace. Market campaigns by ENGOs were described as 'weapons' (Richard Colbeck, Afternoon Session 13 Jan, Select Committee 2013: p.10) and environmentalists as 'extremists' (Jim Wilkinson, Morning Session 12 Jan, select Committee 2013: p.12). Both resource development and conservation discourse coalitions agreed on the need to bring about 'peace', and end 'the crippling impact that this conflict has had more broadly on Tasmania' (Philip Pullinger, 8 April, Legislative Council Committee 2011 p.29). Advocating enabling legislation to the Tasmanian Parliament's upper house, Forest Industries Association CEO Terry Edwards said of its possible failure, 'the outcome of that scenario would be ... [a return] to that war footing where we are at each other's throats, no longer talking to each other and throwing punches or grenades across the barricades' (Afternoon Session 15 Jan, Select Committee 2013: p.41). Bob Annells, the chair of Tasmania's state-owned forest management company, concluded 'while the TFA itself is not perfect, it does represent a consensus between two deeply divided parties. As such, it is in its own way a breakthrough and should allow Tasmania move on at last from what many call the forest wars' (Afternoon Session 16 Jan, Select Committee 2013: p.31).

Significantly, the storyline of the cost of conflict did not undermine either discourse coalition. Storylines function as 'identity markers' for social groups, and often imply a shared 'other' (Nelson and Kinder 1996). Despite efforts to frame the peace negotiations as involving a range of interests, even at the end of the peace process participants still referred to 'our side'.[6] The initial discourse coalitions remained in place even when those who had been party to the negotiations had to confront a new collective 'other' in the form of a hostile Legislative Council, who threatened not to pass enabling legislation for the agreement.[7] Shifting out of the ruts of polarisation in order to reach a settlement was, for some, a threat to long-held identities. As Australian Conservation Foundation CEO Don Henry put it, 'We have all had parts of our constituencies that are very uncomfortable from shifting from business as usual' (Morning Session 12 Jan, Select Committee 2013: p.9).

The peace process was instigated and enacted in a sub-political space outside the dominant power structures of government or scientific technocracy. Possibly as a result, some of the strongest critics of the peace process were those whose traditional roles within these power structures were usurped. 'In ecological terms', the negotiated outcomes would make Tasmania 'the unwitting victim of an unprincipled victory of prejudice, dogmatism, opportunism and naivety over science', submitted a forestry ecologist to the Legislative Council hearing (Grove 2012). Professional foresters lamented their exclusion from the peace process (see Afternoon Session 24 Feb, Select Committee 2013: pp.32-60), and politicians expressed concern about the undemocratic nature of the process (Tony Mulder,

6 See for example Jane Calvert (Morning Session 16 Jan, Select Committee 2013: p.51), refer to 'our side', the pro-forestry discourse coalition, in the negotiations.
7 The Legislative Council is the Upper House of the Tasmanian Parliament, with a constitutional responsibility for legislative review.

Afternoon Session 24 Feb, Select Committee 2013: p38). Notably, industry players in particular had shifted support from traditional authority (political) arbitration to this form of sub-political risk negotiation. It was now considered that long sought certainty in the operating environment was best delivered through risk negotiation (Evan Rolley, Afternoon Session 28 Feb, Select Committee 2013), and that even if the agreed outcome was not optimal from a scientific perspective, the certainty of any agreed position was better for employment prospects than endless negotiation (Jacki Schirmer, 6 Feb, Select Committee 2013).

Ultimately, the agreement negotiated through the peace process was to be short-lived – a centre-right Liberal government elected in 2014 in Tasmania sought, in rhetoric at least, to reimpose a government-arbitrated position. It repealed the Tasmanian Forests Agreement Act soon after the election. However, over three years later, much that was changed as a result of the agreement is still in place in either form or substance. The groundwork laid in the peace process, of resolving underlying values conflicts and dysfunctional relationships, may have contributed to this robustness. It is also possible that the longevity of these outcomes reflects the structural changes to markets that helped catalyse the peace negotiations.

4.0 Insights for environmental risk conflicts

In this article, we have provided a novel conceptualisation of polarisation in environmental risk conflicts as the formation and perpetuation of 'ruts' in which similar patterns of storylines, values and discourse coalitions re-occur in subsequent conflicts. We have shown that the ruts of the forestry debate continue to be seen in Tasmanians' responses to climate change, despite the differences between these issues. We have examined a moment in time when players in this conflict rose out of the ruts in order to conduct a successful process of negotiation. This example both informs the discourse around environmental polarisation, and provides insights that are more broadly applicable. In the following, we discuss three key insights, and suggest how they might be applied to polarisation about climate change and other environmental risk conflicts:

- The sub-political negotiating space might be better suited for disrupting polarisation than traditional democratic authorities.
- Effective risk negotiation between polarised discourse coalitions requires a mutual understanding of the socially constructed nature of risk definition, and recognition that there is no one 'rational' or 'objective' way of defining the risk.
- Disruptive 'bumps' in the political or economic environment can provide opportunities for novel discourse coalitions and storylines to take hold.

The first insight comes from recognition that in reflexive modernity, traditional authorities no longer have the power to arbitrate social change. This is evident from the failure of the RFA to end Tasmania's forestry conflict. It suggests traditional top-down approaches are unlikely to disrupt polarised discourses alone. The kind of sub-political negotiation generated by the peace process is consistent with Jasanoff's (2003 p.398) call for integration of the sub-political and democratic, 'so as to achieve a humane and reasoned balance between power and knowledge, between deliberation and analysis'. Healy (1999) describes a model for 'post-normal' politics in which the role of elected government is to facilitate further democratised processes of sub-political decision-making, and Stevenson and Dryzek (2012) argue for a democratic practice that aspires to 'inclusive, competent and dispersed reflexive capacity'. However, it is not always in the interests of political parties to disrupt polarisation or to interrupt ruts. Thus, initiation of sub-political negotiation may need to come from sub-political players. This means there will also be a need for negotiation between government and sub-political players, especially when government action is required to make necessary change. In the peace process, the sub-political was supported by the Labor/Greens state government, who had clear political motives to do so, as noted above, but was rejected by the new Liberal government in an effort to regain traditional democratic authority and electoral advantage.

Novel discourse coalitions have the potential to begin transformative sub-political negotiations, outside the traditional hierarchies of politics and science. In the context of climate change, our analysis suggests that there is potential for effective negotiation on climate change at the sub-political level. One example of existing sub-political negotiation is between ENGOs and banks who fund fossil-fuel developments, such as the North Dakota pipeline in the US and the Carmichael coal mine in Queensland, Australia. In the former case, the public is being urged to boycott banks who support the project, while in the latter, several banks have been persuaded to pull out of funding agreements. There is potential to expand this sort of negotiation into local climate change sub-conflicts – for example around pollution (such as in run-off from intensive farming activities) and deforestation (for example in development of palm oil plantations).

Sub-political approaches also have challenges. There are significant tensions between sub-political negotiation and democratic ideals that are not reconciled at a theoretical level (e.g. de Vries 2007, Mouffe 2002). One of the criticisms of the peace process during this period was that it focused on key combatants but excluded other interests (Kanowski 2012). Groups including private forest owners and traditional political interests criticised the role of non-elected players in the decision making as undemocratic. While this is not supported by the obvious participation of the democratically elected state and federal governments in passing enabling legislation and dispersing funding for the agreed changes, the longer term failure of the process to survive the subsequent election could in part be attributed to ongoing presence of groups who felt excluded. It shows that processes that seek to disrupt polarised ruts will be vulnerable to any disaffected parties who can draw on the power of the established ruts to pull players back to the *status quo*. This highlights the importance of cultivating trust in sub-political processes (Healy 1999), especially through careful attention to who is represented, how and why.

The second insight from our analysis is that for adversaries to become partners in the negotiation of agreed risk, they must understand that risk definitions are socially constructed. This realisation (central to reflexive modernisation) entails the mutual understanding of divergent values and their importance to social identities. By building relationships between members of different discourse coalitions and promoting alternative storylines, the initiatives of FSC and Our Common Ground were important facilitators of this possibility in the peace process. This is consistent with Hoffarth and Hodson's (2016) suggestion that efforts to disrupt polarisation about climate change be 'not ideologically threatening and … [emphasize] intergroup cooperation'. Our analysis suggests (in line with the theory of Beck and Giddens) that the conflicting storylines of the sanctity of the natural environment versus the sanctity of traditional social order may be repeated across many environmental risk conflicts. Both of these storylines predicate the existence of a higher power (and higher responsibility). However, reflexive modernisation requires taking responsibility for defining the risk ourselves, in the full knowledge that our values are relative. In the peace process, both discourse coalitions acknowledged the legitimacy of the other's concerns in order to negotiate the development and adoption of a shared storyline of the cost of conflict. Together with the sub-political focus of the negotiations, this supports our suggestion that the peace process can be seen as an experiment in reflexive modernisation. Partnership in negotiation does not imply that differences between the discourse coalitions are overcome, but that the need to move forward is given greater precedence.

In the context of climate change, the insight that risk definitions are socially constructed shows that there are significant challenges to the use of purely scientific arguments in order to reconcile polarised discourses. As O'Lear (2016) notes, while scientific storylines dominate, the multiple ontologies of climate change operating in society are kept hidden from debate, and cannot be reconciled. Scientific storylines are central to the dominant framing of climate change, but when they focus on facts without acknowledging values, they are not open to negotiation – they can only be accepted or doubted. Storylines that focus on the impacts of climate change on issues in society that may have shared values across resource development and environmental discourse coalitions, such as health and security, are more likely to enable negotiation of risk definition between polarised discourse coalitions.

The peace process case study suggests that shared storylines can in turn be useful for facilitating the development of novel discourse coalitions involving a new mix of players. When dealing with entrenched discourse coalitions, the power of an empathetic move by a previously polarised adversary should not be discounted. Dolšak and Prakash (2016) argue that reaching out to the potential 'losers' in polarised conflicts has the potential to disrupt policy deadlocks in climate change. While it is challenging to sideline adversarial storylines that have become strongly entwined with one's social identity – such as opposition to carbon-intensive development, in the case of climate change – acknowledging the economic and social losses from climate change mitigation actions could help to open a space for negotiation.

The final insight of this article is to recognise that 'bumps', or stochastic events that disrupt business-as-usual, can be harnessed as transformative moments in the conflict, enabling the disruption of polarised ruts through the formation of new sub-politics. During business-as-usual, the risk to any first mover in trying to open a space for negotiation is that they are likely to be seen as making a move that is in the interest of perpetuating the established storylines of their discourse coalition. Therefore, change requires an action that does not appear to be from within the 'game'. This is why a disruptive 'bump' might be useful allowing alternative storylines and novel coalitions an opportunity to gain traction. Our Common Ground and FSC had their roots in the conservation discourse coalition, and were seen by some in the resource development coalition as a front for ENGOs. Despite this, the disruptive 'bump' of the global financial crisis and Gunns' subsequent collapse made many in the forest industry re-assess their options, opening up an opportunity for the alternative storylines promoted by processes such as FSC and Our Common Ground to be considered. In relation to climate change, market shifts, extreme weather events or political changes could be harnessed as opportunities for transformation. The challenge is to build relationships and prepare alternative storylines in order to be ready to take advantage of the opportunities stochastic events can provide.

5.0 Conclusion

In Tasmania, the development of polarised storylines and discourse coalitions around environmental risk conflicts has created conditions that affect the formation of subsequent conflicts. In other words, environmental risk conflicts have carved out 'ruts' that persist long after the resolution or relevance of the dispute. Our conceptualisation of 'ruts' is a set of conditions that has its own momentum – comprising of storylines that appeal to certain values and definitions of the environment, and are tied to the social identities of certain groups of people. The survey results and case study in this Tasmanian example show how these are perpetuated through longstanding discourse coalitions. Polarisation between those whose predominant concern is maintaining social order and traditional authority, versus those who prioritise the intrinsic value of nature over its use as an economic resource, is repeated in environmental risk conflicts across the globe. The Tasmanian example shows that in the case of forestry, new coalitions of players from outside traditional systems of authority succeeded in shifting the discourse out of the ruts of polarisation, at least for a time, where science and government had failed. Our study suggests that the sub-political negotiation of new storylines is useful in disrupting polarised discourse coalitions. The greatest opportunities for negotiation may be catalysed by disruptive 'bumps'. The challenge for players in polarised discourses is to be prepared to acknowledge the legitimacy of divergent values, and to seek framings that sidestep, rather than challenge strongly held conflicting values. We do not suggest that this should be an attempt to move to a post-polarised or rut-free deliberative democracy, but a pragmatic response to the 'ineradicable character' of power and antagonism (Mouffe 1999) as expressed in the development of the ruts.

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Supplementary Material

Hobart Values Survey: Method

The survey sample was a non-probability sample of 522 adults in the Greater Hobart region. The majority of participants volunteered to complete a web-based survey, which was advertised in local print and radio media, through third party organisations such as Rotary clubs, and through Facebook and Twitter. To engage participants less likely to access an internet survey, 50 participants were drawn from community centres, Retired Services League (RSL) clubs and local markets, where paper and face-to-face surveys were carried out. The sample contained more women (63%) than men (37%), but was a good reflection of the age demographics of the Greater Hobart population. The sample contained a greater proportion of people with tertiary educational qualifications than is present in the population. While this was not a representative sample, non-probability samples can be 'fit for purpose' if the aim is to examine the interaction of personal characteristics and their affect on a specific opinion or behaviour (Baker et al 2013).

Survey questions used in this study

Are you male or female? Male ☐ Female ☐

What is your age? 18-29 ☐ 30-49 ☐ 50-64 ☐ 65 or older ☐

What is the highest level of education you have completed?

Did not complete high school ☐ Year 10 ☐ Year 12 ☐

TAFE or vocational qualification ☐ University undergraduate qualification ☐

Postgraduate qualification ☐

How often do you use each of these media sources to find out about the news?

	1. Never	2. Rarely	3. About once a week	4. Several times a week	5. About once a day	6. Several times a day
ABC or SBS television, radio or websites	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
Commercial television (e.g. WIN, Southern Cross)	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
Commercial radio (e.g. Heart 107.3, Sea FM, HO FM)	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
The Mercury	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
The Australian, Daily Telegraph or Herald Sun	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

The Age or Sydney Morning Herald	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
Other Australian news media (e.g. Australian Financial Review, Crikey, the Guardian, Tasmanian Times)	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
International news media (e.g. New York Times, BBC)	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
News.com.au website	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
Social media such as blogs, Facebook or Twitter	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

Of these industries, please tick the FOUR you think are the MOST IMPORTANT to Tasmania’s future prosperity.

Metals processing	☐	Fisheries and aquaculture	☐
Tourism	☐	Agriculture	☐
Manufacturing	☐	Information and communications technology	☐
Forestry	☐	Education and training	☐
Mining	☐	Financial services	☐

Please CIRCLE the industry above that you think is the LEAST IMPORTANT to Tasmania’s future prosperity.

How concerned, if at all, are you about climate change, sometimes referred to as ‘global warming’?

Not concerned at all	Not particularly concerned	A little concerned	Somewhat concerned	Very concerned	Extremely concerned
1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

Below are some descriptions of different people. How much like you is the person described in these sentences?

	1. not like me at all	2. not like me	3. a little like me	4. somewh at like me	5. like me	6. very much like me
Thinking up new ideas and being creative is important to them. They like to do things in their own original way.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is important to them to be wealthy. They want to have a lot of money and expensive things.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They think it is important that every person in the world be treated equally. They want justice for everybody, even for people they don't know.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is very important to them to show their abilities. They want people to admire what they do.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

It is important to them to live in secure surroundings. They avoid anything that might endanger their safety.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They like surprises and are always looking for new things to do. They think it is important to do lots of different things in life.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They believe that people should do what they're told. They think people should follow rules at all times, even when no-one is watching.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is important to them to listen to people who are different from them. Even when they disagree, they still want to understand other people.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They think it's important not to ask for more than what you have. They believe that people should be satisfied with what they have.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

Having a good time is important to them. They like to 'spoil' themselves.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is important to them to make their own decisions about what they do. They like to be free to plan and to choose their activities for themselves.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It's very important to them to help the people around them. They want to care for other people.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
Being very successful is important to them. They like to impress other people.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is very important to them that their country should be safe from threats from within and without. They are concerned that social order should be protected.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They look for adventures and like to take risks. They want to have	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

an exciting life.						
It is important to them always to behave properly. They want to avoid doing anything people would say is wrong.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is important to them to be in charge and tell others what to do. They want people to do what they say.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
It is important to them to be loyal to their friends. They want to devote themselves to people close to them.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They strongly believe that people should care for nature. Looking after the environment is important to them.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
Religious belief is important to them. They try hard to do what their religion requires.	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐
They seek every chance they can to have fun. It is important to them to do things that	1.☐	2.☐	3.☐	4.☐	5.☐	6.☐

give them pleasure.						

Binary logistic regression

We asked participants to select industries that they think are most and least important to Tasmania's future prosperity. We used binary logistic regression to compare the responses of those who think that forestry is one of Tasmania's most important future industries (pro-forestry) with those who think that forestry is the least important industry for Tasmania's future prosperity (anti-forestry).

We then conducted the same analysis to compare groups with high and low levels of concern about climate change. These groups were derived by creating a dichotomised variable based on participants' responses to the question 'How concerned (if at all) are you about climate change, also known as global warming?' Those who answered on the lower end of the scale – 'not at all' (1), or 'not particularly' (2), (referred to in the analysis as low/no concern about climate change) were compared with those who answered on the upper end of the scale – 'very' (5) or 'extremely' (6) concerned (referred to as high concern about climate change).

We initially included all demographic, media and values variables in the model. The 21 items comprising Schwartz' (2003) Portrait Values Questions were dichotomised for the purpose of analysis, using the mean response across the 21 items for each participant as the central point. This follows Schwartz' advice to correct for individual differences in use of the response scale, so it is the relative importance of each value to an individual that is measured (Schwartz 2003 p.275). It was necessary to reduce the number of variables to avoid problems of multicollinearity. Variables that were entered into the model but were found not to be significant were tested against models containing only significant predictor variables. This process allowed us to compare several models, resulting in a final model for each dependent variable containing only variables that significantly improved the fit of the model. Dependent variables were also checked for multicollinearity. The resulting models are estimated as accounting for 28 per cent of the variation for polarisation about forestry, and 36 per cent of the variation for polarisation about climate change. Below are detailed statistical tables for these models (a version edited for clarity is presented at Table 2 in the main article).

Binary logistic regression models showing the variables that predict likelihood of belonging to polarised groups. Model 1 compares the *pro-forestry group* with the *anti-forestry group*. Model 2 compares the *low/no climate change concern* and *high climate change concern groups.*

Model 1: Pro-forestry cf. anti-forestry

Predictor variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	**Upper**
Gender: Male (cf. female)	0.408	0.385	1.126	1	0.289	1.504	0.708	3.196
Commercial media use (weekly cf. rarely/never)	0.562	0.403	1.944	1	0.163	1.754	0.796	3.863
Commercial media use (daily cf. rarely/never)	1.676	0.563	8.875	1	0.003	5.347	1.775	16.109
Public media use (weekly cf. rarely/never)	-0.961	0.579	2.759	1	0.097	0.382	0.123	1.189
Public media use (daily cf. rarely/never)	-1.553	0.521	8.878	1	0.003	0.212	0.076	0.588
Values **variables**[a]								
Universalism-equality: Concern about equality and justice	0.568	0.687	0.685	1	0.408	1.765	0.460	6.780
Universalism-nature: Care for nature and environment	-1.654	0.593	7.768	1	0.005	0.191	0.060	0.612

Security-order: Concern for national security, protecting social order	1.132	0.405	7.799	1	0.005	3.101	1.401	6.861
Constant	-0.185	0.794	0.054	1	0.815	0.831		

Model 2: Low/no concern about climate change cf. high concern about climate change

Predictor variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
Gender: Male (cf. female)	1.393	0.460	9.166	1	0.002	4.026	1.634	9.918
Commercial media use (weekly cf. rarely/never)	0.332	0.489	0.462	1	0.497	1.394	0.535	3.631
Commercial media use (daily cf. rarely/never)	1.365	0.625	4.774	1	0.029	3.916	1.151	13.326
Public media use (weekly cf. rarely/never)	-0.307	0.706	0.190	1	0.663	0.735	0.184	2.933
Public media use (daily cf. rarely/never)	-1.473	0.680	4.700	1	0.030	0.229	0.060	0.868
Values variablesa								
Universalism-equality: Concern about equality and justice	-1.340	0.658	4.150	1	0.042	0.262	0.072	0.950
Universalism-nature: Care for nature and environment	-2.713	0.671	16.333	1	0.000	.066	.018	.247
Security-order: Concern for national security, protecting social order	1.463	0.583	6.296	1	0.012	4.317	1.377	13.533
Constant	0.195	0.877	0.049	1	0.824	1.215		

[a] Values variables are dichotomous: i.e., value is of greater than average importance cf. less than average importance to the respondent (see supplementary material for more detail on the process of analysis).

Neither age nor education were found to be significant predictor variables for either climate change concern or polarisation on forestry, and so were excluded from the final model. Media use was measured using composite categorical variables for frequency of commercial television and radio, and ABC and SBS media. Dichotomised values statements (where the data showed whether each value proposition was one of the most, or least important values for each participant) included in the final model were: Universalism-equality 'They think it is important that every person in the world be treated equally. They want justice for everybody, even for people they don't know'; Universalism-nature 'They strongly believe that people should care for nature. Looking after the environment is important to them'; and Security-order 'It is very important to them that their country should be safe from threats from within and without. They are concerned that social order should be protected';

The results of the two binary logistic regression models are shown in Table 2 in the main article. Gender was not significant in predicting polarisation on forestry. However, those with a low level of concern about climate change were more than four times as likely to be male (OR 4.03 $p<0.01$). Respondents who were pro-forestry were more frequent users of commercial television and radio than those who were anti-forestry. Pro-forestry respondents were more than five times as likely to use commercial media every day (OR 5.35 $p<0.01$). Conversely, they were almost five times less likely to use ABC or SBS every day (OR 0.21 $p<0.01$). This pattern of media use is similar to that found in respondents with low or no concern about climate change, who were almost four times more likely to be daily commercial media users (OR 3.92 $p<0.05$) , and four times less likely to use ABC or SBS every day (OR 0.23 $p<0.05$).

Polarised attitudes to nature are a feature of both the forestry and climate change debates. People who are pro-forestry were almost five times less likely to prioritise caring for nature and the environment than those who were anti-forestry (OR 0.19 $p<0.01$). Those with low or no concern about climate change are even less likely to care about nature (OR 0.07 $p<0.001$). A shared concern is national security and social order, both pro-forestry (OR 3.10 $p<0.05$) and low/no concern about climate change groups (OR 4.32 $p<0.05$) being more than twice as likely to prioritise security.

One other value emerged as a significant predictor of polarisation on climate change but not forestry. Greater concern for social equality (reciprocal OR 3.85 $p<0.05$) predicted high levels of concern about climate change, reflecting that this is seen as a threat to the less advantaged members of global society as well as to the environment.

Appendix C. New Zealand Forestry Journal key word specificity

Figures are the TXM specificity score for each word for that period. Negative scores (blue) indicates the word appeared less frequently in a specific period than over the whole corpus period, while positive scores (orange) indicate the word appeared more often in this period then in the whole. The software programmers consider scores of between 2 and -2 are not statistically significant hence those that are shown in the lighter colour.

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
afforestation	621	-1.4	-3.6	0.5	-0.9	-1.4	-0.6	-0.8	0.5	1.9	0.7	2.0	0.4	0.7	-2.7	-1.4	-6.9	8.4	1.8
Agricultural	143	-1.4	-0.8	0.7	-0.3	0.4	0.6	-0.3	1.8	-2.3	-1.7	-0.4	-0.3	4.5	0.7	-0.5	-1.0	-0.3	0.2
agricultural	414	-3.4	-0.4	0.7	-2.3	-3.0	-0.4	0.5	1.1	-1.1	0.5	0.7	0.5	1.2	-0.7	-0.6	-1.1	2.9	1.9
Agriculture	356	-3.4	-3.9	-1.6	-0.3	-0.9	3.5	1.2	-0.4	-4.6	-4.1	-2.7	-1.0	3.0	-1.8	2.1	1.9	3.8	6.9
agriculture	393	-0.9	-0.4	-2.8	-2.2	-2.1	-3.9	-0.3	4.6	-0.4	-0.8	-0.6	-0.4	2.9	0.3	0.7	-1.7	2.4	4.3
change	1,221	-7.3	-4.2	-7.0	-4.3	-10.9	-4.1	-2.4	-10.8	-3.2	-6.3	-1.9	5.4	5.7	0.4	14.8	1.0	22.1	44.2
conflict	143	-0.9	-2.0	-0.5	-0.6	-1.8	-1.6	0.7	-4.0	-0.7	-0.4	3.6	8.4	5.1	1.5	-1.0	-1.0	-3.2	-1.8
Conservation	361	-3.4	-3.9	-3.5	0.9	0.9	-5.0	0.4	-4.7	-7.8	0.4	-4.4	-0.9	8.7	6.9	6.4	-0.3	2.7	2.9
conservation	739	-7.6	-10.4	-8.4	-3.8	-1.5	-3.8	0.4	-10.3	-10.6	1.1	2.4	1.3	8.5	9.7	17.3	-0.5	0.6	1.0
country	2,108	-0.4	-0.7	7.3	-1.1	0.6	-0.5	5.7	0.7	-2.1	0.6	-0.4	-2.3	0.7	1.6	-2.1	-4.6	-2.0	-0.3
crops	583	-4.8	-2.3	-1.3	-2.2	-2.2	0.6	-3.5	-2.1	0.7	20.5	5.0	6.1	-1.0	1.7	-4.1	-1.1	-4.2	-2.1
crown	643	0.6	4.2	0.4	-1.6	2.4	-1.4	-1.5	23.3	1.8	-1.0	-12.9	0.6	-4.4	-6.9	1.1	-1.6	-0.4	-6.6
cut	996	5.2	5.8	27.2	0.5	1.0	4.1	-5.1	0.3	1.2	-4.0	-0.7	-0.7	-1.4	-1.4	-2.9	-2.8	-6.7	-5.6
cutting	584	3.8	1.4	12.2	2.3	-0.4	1.7	-6.2	0.3	1.0	-0.3	-1.6	-0.3	-0.5	2.1	-5.0	-2.3	-3.4	-3.5
deer	1,089	-6.4	0.3	-9.1	-1.6	-6.9	8.6	1.9	98.2	-6.6	2.1	-22.1	-26.3	0.4	22.9	-5.4	-15.3	-21.4	-3.2
degree	642	-0.8	-0.3	-1.3	-0.4	0.5	0.3	0.5	-0.4	1.0	-1.2	1.1	1.0	1.1	-0.5	2.6	-2.3	-1.0	-1.3
demand	907	-3.7	-4.4	-2.9	-1.4	-3.8	-3.4	-8.7	-0.4	1.4	0.9	0.3	10.7	3.2	-0.7	-2.9	2.4	7.4	4.6
development	2,296	-5.1	-0.5	-6.5	-6.6	-5.5	-0.6	-2.4	-0.6	-0.4	2.6	6.1	6.5	0.5	1.5	2.8	0.6	-1.3	0.3
diversity	163	-1.6	-1.5	-0.7	-1.3	-1.7	-1.6	-0.3	-4.8	-2.2	-1.4	0.3	14.4	-0.8	0.9	1.2	2.0	2.4	-0.3
Douglas	1,299	-1.7	-3.5	-6.1	-1.2	-12.9	1.1	-2.3	-7.8	82.9	-5.8	48.0	-3.9	-1.0	3.5	-16.6	-2.0	-5.4	-6.7

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
ecological	396	-1.4	-1.5	-2.0	-0.5	2.9	0.6	1.1	-2.5	-1.5	0.8	0.4	2.2	-1.1	2.8	0.5	0.7	-2.8	-0.9
Ecology	136	-1.3	-1.9	-2.4	-1.1	-0.9	-0.8	-3.4	-2.0	-2.9	-1.5	-1.6	2.4	-0.5	2.0	-2.4	0.7	22.9	6.6
ecology	173	0.3	-1.6	-3.1	-0.7	1.8	0.8	0.3	-0.6	0.3	-0.6	-0.3	0.8	0.3	3.0	0.6	-1.5	-0.5	-0.5
Economic	133	0.3	-1.1	-2.3	-1.0	-3.8	-1.4	-1.0	-0.5	-0.6	-0.3	-2.4	0.4	4.0	4.4	0.7	1.6	2.5	0.5
economic	1,273	-5.0	-2.7	-1.6	-2.0	-7.0	-1.8	-2.9	-1.2	-3.2	1.3	4.4	3.2	1.7	8.0	7.6	-1.5	-0.3	2.0
Economics	135	1.0	-1.2	-0.7	-1.1	-3.9	-2.7	-4.2	0.4	-0.3	1.6	-0.7	0.4	6.0	2.9	0.3	-0.3	0.3	0.5
economics	249	-1.5	-1.0	-1.5	-0.8	-2.5	-1.5	-5.0	1.0	0.4	2.4	2.9	4.6	-1.5	2.2	-1.5	-1.7	2.7	-0.8
economy	393	-3.2	-2.3	-4.8	-1.6	-0.7	1.2	-0.4	1.9	-1.5	-1.4	0.8	-0.8	0.3	9.0	-0.3	-2.4	2.2	2.1
ecosystem	147	-2.2	-2.1	-2.6	-1.2	-4.3	-3.0	-1.0	-6.3	-2.4	-0.5	12.9	6.9	-1.7	-0.7	-0.5	0.6	7.6	0.9
ecosystems	166	-2.5	-2.3	-2.9	-1.3	-4.8	-4.5	-6.6	-7.1	-4.7	-0.9	9.8	10.8	-1.1	2.8	2.0	1.6	3.5	0.5
efficiency	252	-0.9	-1.0	-0.7	-2.0	-2.1	-3.3	-2.3	0.3	-0.6	7.2	0.3	-0.9	7.9	0.9	2.2	-1.7	-0.4	-0.5
efficient	257	0.6	-0.8	-1.0	-2.0	0.5	-2.4	-1.1	1.2	1.0	1.6	-0.3	0.6	-0.6	-0.6	0.3	0.5	-0.6	1.0
energy	472	-2.5	-4.5	-8.3	-2.0	-10.9	-10.1	-12.6	-12.9	-7.2	-10.4	31.8	13.8	-2.2	0.4	1.2	1.4	1.6	50.8
Environment	230	-3.5	-3.2	-4.1	-1.8	-5.4	-6.3	-9.2	-9.9	-5.3	-1.7	-1.5	-1.3	4.9	4.2	22.0	2.5	16.2	4.0
environment	570	-7.2	-5.7	-2.7	-3.4	-5.4	-4.8	-1.4	-2.3	1.5	3.2	-1.8	0.4	0.8	4.3	11.7	1.3	5.6	0.3
Environmental	168	-1.7	-2.4	-3.0	-1.3	-3.8	-4.6	-6.7	-7.2	-2.9	-0.5	0.4	-0.5	0.3	1.6	14.5	6.4	9.3	1.7
environmental	788	-11.8	-9.6	-13.9	-6.2	-21.0	-14.0	-21.9	-21.2	-6.2	-1.2	3.1	-1.5	6.4	21.4	28.4	4.3	39.0	5.5
erosion	754	-5.5	-2.0	0.9	-0.4	1.9	-2.8	3.8	0.5	-1.6	2.2	2.8	-5.0	0.4	4.0	-2.0	-5.5	1.1	-1.0
exotic	1,905	-3.5	-0.6	8.6	-3.1	-3.5	17.5	5.9	-1.7	-4.5	0.4	7.3	11.0	2.8	-6.2	-12.5	-17.6	-7.5	-4.3
experimental	230	1.3	-0.3	2.3	-0.2	-0.7	2.4	3.9	-0.9	0.7	-1.0	-1.0	-1.0	-0.9	-0.3	-2.4	-0.6	0.3	-0.9
export	723	-8.3	-2.7	-4.9	-2.0	-8.0	-5.3	-16.9	-1.2	5.1	-0.4	6.5	-2.6	9.7	24.9	-0.3	2.5	-0.8	2.1
exported	104	-0.9	-1.5	-0.7	0.3	-0.5	-0.4	-4.1	-1.6	2.6	-0.8	-0.6	-1.1	3.2	4.7	0.5	0.9	0.6	0.5
exported	104	-0.9	-1.5	-0.7	0.3	-0.5	-0.4	-4.1	-1.6	2.6	-0.8	-0.6	-1.1	3.2	4.7	0.5	0.9	0.6	0.5
exports	465	-7.0	-5.3	-4.4	-1.5	-11.9	-11.2	-11.4	-5.8	27.4	-2.8	1.5	-4.6	8.9	26.1	-1.8	-0.8	14.6	-1.3
failed	170	0.4	-0.3	-0.3	-0.4	-0.9	-0.7	0.4	-0.6	1.1	0.8	0.5	-1.2	1.4	1.0	-1.4	0.5	0.3	-0.8
failure	264	-1.3	-2.7	-0.4	-0.5	-0.3	1.5	0.3	-0.6	2.5	0.4	0.6	2.8	-0.8	0.8	-0.7	-1.9	-0.7	-1.2
FAO	156	-2.3	-2.2	-2.8	-1.2	1.6	-1.9	-6.2	-1.4	0.4	0.7	-1.3	-1.3	-2.5	-2.2	-0.9	2.9	16.1	12.5
Farm	193	-2.9	-2.7	-3.4	-0.9	-3.6	-0.8	-0.9	3.9	-1.1	-0.5	-1.4	-1.6	1.2	3.6	3.7	0.7	1.7	1.7
farm	710	-10.7	-3.9	-3.8	-1.9	-3.7	5.5	-1.5	15.5	-3.0	-5.5	1.3	-3.4	0.3	6.2	0.5	0.9	2.0	-0.3
farmer	131	-0.8	-0.4	-1.5	0.7	-0.4	1.9	-1.0	2.9	-0.8	-1.8	-0.8	0.4	-0.7	1.8	-0.6	-0.6	1.8	0.3

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
farmers	286	-2.5	-1.3	-1.6	-1.0	-2.4	-1.2	-2.7	1.9	-2.7	-3.3	-2.3	-0.9	8.9	7.8	2.0	-0.5	7.1	0.3
farming	562	-4.6	-6.6	-7.4	-3.4	-8.8	1.1	-2.4	-0.4	0.4	-1.6	7.3	14.7	3.9	0.3	-2.2	-5.3	4.0	1.3
farms	162	-1.1	0.6	-1.0	-0.4	-1.7	0.4	-0.8	-0.6	-1.7	-0.8	-1.1	-0.8	0.5	1.2	1.2	0.8	9.7	0.3
farms	162	-1.1	0.6	-1.0	-0.4	-1.7	0.4	-0.8	-0.6	-1.7	-0.8	-1.1	-0.8	0.5	1.2	1.2	0.8	9.7	0.3
felling	526	-3.0	-1.3	1.3	10.7	5.1	5.9	0.5	-0.6	-1.3	-0.3	0.7	9.3	-5.7	-2.4	-2.0	-9.6	-10.4	-4.3
fibre	144	-0.3	-1.3	-2.5	-0.6	-1.8	-0.9	-3.7	-0.9	-1.8	1.4	2.8	-1.9	-0.6	1.2	1.3	5.3	1.5	1.7
Fig	758	-5.0	-5.6	-8.7	-3.2	-9.3	-3.7	1.7	6.8	23.4	0.8	0.4	9.4	-2.0	-4.4	-6.0	3.8	-2.1	-3.5
Fire	127	-0.2	-1.1	-0.4	0.7	5.7	-1.0	-0.7	-1.1	-0.8	0.8	-0.3	-0.8	1.6	-0.5	-0.4	0.6	-0.3	-0.9
fire	1,069	-0.5	-2.2	0.7	-0.7	13.5	1.7	24.8	-1.7	-0.3	1.1	-1.1	-7.5	0.5	-15.2	-6.9	-0.7	-1.6	-5.7
FOREST	409	-4.1	-1.6	0.7	-0.3	-1.7	0.9	5.3	-0.7	4.7	2.4	6.2	1.0	0.4	-2.0	-6.7	-8.6	-9.3	-5.0
Forest	10,643	-18.0	-39.8	-5.4	-5.7	0.4	92.4	7.0	8.6	-0.4	49.3	-26.5	-9.9	5.2	-10.9	-0.7	-1.4	-16.9	-11.8
forest	13,608	-8.1	-3.9	-1.2	-15.8	0.3	7.5	5.5	-28.0	-6.9	-0.8	3.6	-2.4	-1.8	2.1	7.5	24.9	-0.4	8.0
forested	149	-2.2	0.3	1.1	-0.6	-0.8	-0.5	0.5	-0.6	-0.3	1.8	1.4	-2.6	0.9	1.1	-0.3	-1.6	0.6	-0.7
Forester	131	-1.2	-1.1	-0.4	-1.0	-0.8	0.4	1.0	0.8	0.5	3.1	-0.8	-0.6	0.7	0.6	-2.3	0.6	-0.3	-0.5
forester	828	1.9	1.4	1.8	0.4	17.0	8.5	10.4	-0.4	-3.2	-2.5	-2.9	-9.6	-2.2	-3.7	-3.3	-2.5	-2.1	-4.1
Foresters	402	-0.9	-0.4	-0.3	0.9	2.8	0.3	1.3	-1.5	-5.0	-0.7	-0.3	1.2	10.8	-0.9	-1.9	0.4	-2.1	-1.5
foresters	1,213	0.3	-3.8	1.5	-0.6	4.5	-0.4	-0.6	-1.3	-9.9	0.4	1.5	0.4	0.9	1.5	0.5	-0.4	-0.3	0.3
FORESTRY	879	-2.7	-5.7	-5.8	-4.0	-12.0	-5.1	-2.3	-19.7	-13.8	-0.7	23.7	3.8	32.9	29.0	-0.8	1.8	-9.6	0.8
Forestry	4,358	3.7	-3.8	-5.5	-2.2	-1.0	-2.3	-18.7	-12.2	-46.2	-19.8	-36.0	-12.9	22.0	52.4	83.3	19.2	10.3	19.5
forestry	6,415	2.2	-12.1	-16.3	-5.5	-3.2	-16.0	-60.4	-26.4	-31.8	-23.4	-3.5	11.5	20.8	33.3	89.8	20.5	20.0	30.1
FORESTS	149	-2.2	-1.3	-1.2	-0.6	0.8	2.0	1.7	-0.2	-1.1	0.4	11.4	-0.7	0.9	-1.5	-2.7	-3.1	-3.4	-1.8
Forests	1,399	-5.4	-4.6	18.1	1.8	1.0	-0.4	1.0	-1.0	-12.0	-2.2	-0.8	-4.2	4.4	1.0	2.1	-0.3	-0.4	2.3
forests	6,056	-20.4	-12.2	-3.2	-7.9	3.5	15.2	2.4	-7.8	-31.7	-2.3	1.3	-2.5	-1.1	5.5	3.9	6.0	4.7	23.0
future	1,889	0.4	-2.4	-9.7	-4.1	-7.5	-0.3	-6.2	1.1	-0.7	-1.4	1.6	-0.3	0.5	8.2	0.3	10.8	3.4	2.1
generation	187	0.5	0.8	-1.7	-0.8	-1.4	2.6	1.0	-1.8	-0.8	-0.3	-3.4	2.5	-1.0	0.3	-0.5	0.4	1.5	1.8
generations	111	-0.6	-0.5	-0.8	-0.9	1.0	2.1	1.0	-0.4	-2.2	-1.7	-0.2	0.3	0.3	0.4	-0.2	-0.6	1.0	1.0
genetic	333	-5.0	-4.7	-5.9	-2.6	-5.5	-5.8	0.5	-4.9	-1.7	0.4	-1.7	-0.5	-2.6	1.9	23.4	11.6	9.5	-0.5
Germany	104	-0.3	2.2	-0.4	-0.4	3.9	-0.3	-0.5	-2.6	0.3	-0.8	-1.2	1.7	-0.6	0.3	-0.8	0.4	0.4	0.3
government	515	-6.5	-7.2	-5.1	-4.1	-8.4	-14.0	-11.5	-7.7	-5.2	-5.6	-0.3	3.6	0.6	4.5	6.9	5.7	17.4	46.4
Government	1,016	-2.6	-3.3	-6.0	-1.9	-13.1	-6.5	-9.7	-3.9	-7.3	-5.3	-0.3	-2.4	41.4	45.8	11.6	1.3	2.7	0.5

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
Green	113	-1.7	-1.6	-0.5	-0.4	-1.2	-0.3	1.2	0.6	1.6	0.9	-3.2	-0.9	-1.7	-1.5	0.8	-0.4	4.8	1.9
green	678	-2.1	-2.7	1.5	2.2	-2.2	-6.3	0.5	26.8	-0.6	0.8	-6.3	6.2	-9.2	-2.4	-1.2	-5.4	2.6	-0.7
ground	1,286	-0.4	5.6	2.9	5.2	1.0	1.2	21.5	-1.4	-2.6	0.3	-0.3	-0.5	-4.9	-2.3	-1.9	-14.8	-8.3	-1.3
growing	1,387	-3.1	-0.3	1.7	0.4	-3.2	-0.5	-0.5	0.6	1.0	3.1	-1.2	-1.2	1.0	1.0	-1.1	0.9	0.7	-0.9
growth	4,699	17.7	11.3	0.7	-0.5	-7.3	3.4	-8.1	0.6	-0.9	4.4	-3.6	6.9	1.9	-11.4	-9.2	-11.5	0.6	5.0
hardwood	369	-2.9	-4.1	-0.4	-0.5	-2.3	27.2	2.0	-3.0	-0.8	10.2	-4.1	-0.6	-1.6	-1.1	-2.1	0.3	-1.4	-1.6
hardwoods	464	-2.4	-4.4	-1.7	-0.6	-2.8	19.5	18.7	-2.3	-1.6	3.1	0.3	-4.2	-1.1	-0.7	-3.5	-3.8	-2.2	0.6
harvest	512	-6.4	-7.2	-7.7	-4.0	-12.0	-9.2	-14.0	-16.4	-4.7	-8.1	-12.0	0.6	-1.3	2.6	10.9	55.7	49.9	11.7
harvested	229	-3.4	-3.2	-4.0	-1.8	-6.6	-2.3	-3.8	-6.4	-1.1	0.6	-1.8	0.5	0.5	2.3	5.8	10.7	3.9	10.1
harvesting	612	-6.8	-8.6	-9.4	-3.7	-14.7	-7.7	-12.5	-23.0	-7.2	-0.3	-2.1	5.3	0.8	8.5	19.8	24.4	9.8	13.7
height	2,268	-0.4	30.3	0.8	2.6	-1.3	0.3	-2.0	18.0	1.4	13.1	-14.6	-1.1	-2.5	-16.9	-14.3	-28.2	9.2	-7.9
herbicide	140	-2.1	-2.0	-2.5	-1.1	-4.0	-3.8	-5.6	-6.0	-0.5	-4.0	13.1	-1.8	-1.1	-0.4	0.3	-0.7	11.5	23.7
herbicides	156	-2.3	-2.2	-2.8	-1.2	-4.5	-4.2	-6.2	-4.5	-3.4	-0.4	62.3	-1.7	-1.8	-1.6	-0.9	-1.2	0.8	7.1
history	503	0.9	0.5	1.1	-1.3	-0.4	-0.8	0.7	-4.1	-1.4	-0.9	-1.5	3.4	1.4	-0.3	0.5	-0.6	2.6	0.5
history	503	0.9	0.5	1.1	-1.3	-0.4	-0.8	0.7	-4.1	-1.4	-0.9	-1.5	3.4	1.4	-0.3	0.5	-0.6	2.6	0.5
hunters	103	-1.5	-0.8	-1.8	-0.8	-2.1	-2.8	-1.8	0.3	0.9	-1.1	-1.6	-3.1	36.5	3.6	-0.8	-2.2	-2.3	0.5
hunting	263	-2.2	-0.4	-2.8	-1.3	-7.6	-4.2	-1.9	-0.3	-0.8	0.3	-1.1	-2.9	24.1	32.7	0.4	-4.4	-2.1	-1.7
import	127	0.8	1.3	0.6	-1.0	-1.1	-2.5	-2.5	0.4	4.8	-0.5	-1.7	-1.6	0.7	1.2	-0.5	0.6	2.3	-0.9
import	127	0.8	1.3	0.6	-1.0	-1.1	-2.5	-2.5	0.4	4.8	-0.5	-1.7	-1.6	0.7	1.2	-0.5	0.6	2.3	-0.9
imported	163	1.0	3.1	0.7	0.2	-1.7	-1.2	-2.0	-1.3	1.8	-2.6	0.7	-0.8	0.5	0.5	0.3	1.6	1.4	-0.8
imported	163	1.0	3.1	0.7	0.2	-1.7	-1.2	-2.0	-1.3	1.8	-2.6	0.7	-0.8	0.5	0.5	0.3	1.6	1.4	-0.8
imports	198	-1.5	-0.9	-1.4	-0.5	-3.7	-1.8	-3.5	-0.4	17.3	-0.3	-0.8	-5.9	2.0	1.4	-2.4	1.1	7.0	-1.6
Indigenous	190	-2.9	-2.7	-1.8	-0.8	0.8	-0.4	-0.8	-1.9	-1.8	-2.8	1.9	-1.0	0.3	0.3	12.6	4.4	-1.1	1.4
indigenous	1,703	-14.3	-9.1	0.3	-3.6	-4.1	3.7	0.9	-10.5	-14.0	-5.0	51.2	-1.5	0.8	0.7	0.9	18.6	-3.1	0.7
industries	587	-2.7	-1.4	-4.2	-3.6	-3.4	-1.3	0.4	2.2	2.5	7.4	3.9	-0.5	-0.4	0.3	-1.7	-0.5	-0.7	-1.2
industry	1,929	-12.3	-7.0	-3.2	-7.3	-24.5	-20.2	-11.2	-11.7	-4.0	0.5	-1.7	-1.7	-0.3	89.0	19.3	53.4	-0.3	8.2
Institute	2,947	-14.6	-13.6	-16.4	4.1	-0.5	3.0	6.3	3.7	-6.4	-0.5	-11.2	-4.3	20.7	10.4	10.4	2.4	-4.5	-12.5
investment	574	-5.4	-4.9	-8.7	-3.5	-15.0	-7.0	-19.7	-4.4	1.5	-3.6	-4.8	-5.4	0.4	34.9	0.4	66.7	7.2	4.4
Island	1,393	-5.7	-0.8	-1.1	-5.9	-4.0	2.6	4.1	-0.8	-13.3	0.5	6.0	2.2	2.3	4.4	0.3	-2.8	-0.6	-0.6
journal	211	11.7	1.4	-1.5	-0.6	0.7	-4.6	6.4	-4.3	-6.0	-5.5	-2.1	-1.0	4.7	1.7	0.3	0.9	-1.1	-0.8

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
JOURNAL	285	-4.3	-2.3	-1.5	-1.0	-0.5	0.4	7.2	-12.2	-5.8	-2.2	3.7	2.3	-1.9	-5.8	-4.1	15.5	-0.9	9.1
Journal	899	-5.4	-5.9	2.3	0.6	0.6	-0.7	0.7	-2.9	-8.2	-12.2	-11.6	-6.8	5.2	3.2	-0.5	15.0	23.1	6.0
kauri	831	-8.8	6.7	12.5	5.3	11.2	-1.9	19.6	-7.3	-21.9	-7.0	20.9	2.3	-0.6	-11.8	-13.2	-15.9	-11.7	-6.0
knowledge	665	3.1	0.5	-0.4	-2.1	3.4	0.7	-1.1	-3.2	-4.1	0.6	-2.9	-1.1	-2.0	-0.4	0.4	2.3	4.0	3.8
labour	428	-1.1	-2.7	0.5	-0.3	0.5	4.7	-3.4	2.5	-1.1	2.6	2.3	0.5	-1.2	0.9	-3.8	-0.9	-1.3	-2.6
Land	524	-4.8	-7.3	4.4	4.0	-1.3	1.4	-5.2	-1.0	-1.7	-1.4	-2.6	0.6	1.3	2.4	1.4	1.8	3.0	1.2
land	4,407	-14.3	-8.8	1.1	-0.4	-15.9	-2.3	-3.5	-0.3	-10.5	-8.2	0.7	2.0	2.9	2.2	1.4	37.1	23.2	2.3
Lands	304	-1.0	-2.5	5.2	0.5	-3.1	-0.8	-0.3	-0.7	0.8	1.6	0.6	0.9	1.5	0.5	-2.3	-3.6	-2.3	3.0
lands	712	0.5	0.7	14.2	-0.6	-5.9	0.8	27.7	1.4	-5.7	-1.6	-2.7	-3.4	-1.4	-1.2	-5.7	-4.5	1.8	-1.7
Log	175	-2.6	-1.6	-3.1	-0.4	-1.2	-4.8	-3.4	1.0	0.7	-1.3	-0.5	1.1	-0.3	3.8	0.4	17.7	-0.7	-0.9
log	1,410	-7.2	-11.0	-12.3	0.6	-6.8	-11.5	-22.2	-1.0	-0.5	-1.0	0.7	3.7	10.1	4.8	0.5	82.2	1.0	-5.1
logged	282	-0.4	-0.5	-1.5	-1.4	-2.7	12.6	-0.3	-2.1	-4.2	3.1	7.4	-0.7	6.1	-0.8	-2.8	-5.9	-4.3	-2.5
Logging	209	-0.5	-0.5	-2.7	-1.0	-1.4	-2.4	1.2	-1.4	-0.4	0.3	-0.4	7.3	1.5	-0.6	3.6	-0.6	-0.4	-1.2
logging	1,429	-1.3	1.4	-5.9	-5.5	-7.4	-0.7	-0.3	-10.2	-3.6	2.5	29.4	19.7	2.4	1.6	-0.3	-2.7	-7.8	-11.5
logs	1,490	-9.7	-11.2	-5.1	1.3	-4.5	-7.7	-8.1	3.4	7.5	-2.3	-1.3	8.1	5.7	5.5	1.7	13.8	-3.3	-2.7
man	537	13.1	2.1	3.3	-0.4	0.3	0.3	1.6	0.7	-3.9	-0.3	-1.2	1.6	-1.3	-1.2	-3.0	-3.9	-2.8	-0.9
manage	201	-0.3	-0.9	-1.4	-0.9	-3.8	-1.4	-4.2	-2.2	-1.3	-1.0	0.7	-0.3	0.7	0.5	5.2	5.9	3.2	3.2
managed	463	-4.8	-1.1	-2.7	-2.0	-3.5	-0.3	-2.4	-2.0	-3.0	3.4	1.5	0.4	0.4	1.8	0.5	9.2	1.3	1.7
Management	595	-2.4	-7.0	-5.5	-3.6	-5.0	-2.4	-7.4	-4.9	-7.4	-4.3	-2.8	1.1	7.7	5.0	28.0	10.0	7.7	2.0
management	3,529	-25.1	-22.3	-22.4	-9.4	-18.0	-8.2	-3.3	-20.9	-12.6	1.6	10.9	15.4	8.5	4.4	37.9	25.6	3.8	1.0
Maori	447	-0.5	0.3	-7.9	-1.9	-10.2	-3.1	-6.8	3.5	-3.9	-8.9	-1.7	2.2	-1.2	-1.1	24.5	4.6	16.6	-0.7
market	1,482	-15.7	-12.6	-4.8	-5.2	-16.1	-13.8	-22.6	-3.5	-0.4	-5.7	-1.6	-7.0	5.2	17.9	2.9	92.7	41.9	-0.3
markets	660	-8.5	-6.0	-5.8	-4.1	-7.2	-4.7	-7.7	-1.0	0.7	-1.5	-2.0	-3.5	10.0	6.6	0.8	25.9	15.9	1.1
method	930	1.0	3.3	2.6	-0.8	2.2	1.1	1.7	1.0	0.3	-2.2	-1.5	0.9	-1.8	-5.3	-1.9	3.7	-8.1	-2.4
methods	928	5.3	-0.3	-1.1	-0.4	1.1	0.4	3.1	1.6	0.3	2.3	-2.3	-0.6	-2.4	-3.2	-0.5	-2.0	-0.4	-3.5
Mill	124	-0.2	-1.7	-2.2	-0.2	2.6	-1.8	8.3	5.9	0.4	-0.9	-1.0	-2.0	-1.3	-1.7	0.4	-2.6	-1.3	-1.5
mill	387	3.4	-1.4	-0.6	0.8	-0.4	-0.4	-3.9	1.8	-0.6	1.7	11.8	-6.4	-3.0	1.1	0.3	-0.3	-5.5	-2.3
milling	197	10.4	7.6	4.8	-0.3	3.4	2.4	-3.4	-0.8	-3.6	-2.5	-1.5	-3.1	-1.5	-0.3	0.9	-3.1	-2.6	-1.1
mills	281	1.2	0.5	-0.3	-2.2	1.4	-0.6	-3.3	-2.1	0.4	2.4	6.7	-6.0	0.4	2.3	-1.6	1.6	-2.9	-2.5
model	761	-11.4	-9.2	-11.9	-6.0	-18.9	-20.7	-25.5	-19.4	-2.0	-17.0	18.0	69.0	-0.4	-0.3	0.3	3.0	50.0	1.2

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
National	740	-8.6	-7.9	-4.1	-0.8	-3.5	-1.8	0.6	-2.0	-2.4	3.7	0.7	-1.3	4.0	2.3	6.4	1.7	-0.4	5.1
national	846	-4.4	-1.8	-5.9	-1.8	-5.8	-4.0	-8.0	1.7	-3.4	0.3	5.3	1.2	4.1	1.7	8.8	-0.3	-0.6	8.7
native	1,168	7.3	8.5	1.3	-2.2	-4.6	-3.1	-5.3	-18.9	-11.5	-1.0	1.1	0.6	2.3	-0.3	4.5	1.7	16.6	-0.4
Natural	156	-2.3	0.4	-1.3	0.8	0.7	0.3	-1.2	-1.1	-1.2	-2.0	-0.6	1.3	0.8	0.7	1.9	0.7	1.6	0.6
natural	1,547	-2.9	-0.5	-1.1	1.6	0.7	1.8	-0.4	-1.5	-5.6	-2.3	-0.4	5.5	-1.6	0.6	1.9	1.2	1.9	0.4
naturally	300	0.4	4.8	2.3	0.3	3.3	0.6	1.3	-0.5	0.4	-0.5	-0.7	-1.5	-2.6	-1.8	-2.2	-1.3	0.4	-1.5
nature	726	11.9	0.4	-0.7	-2.0	3.2	-0.6	1.1	-0.5	-0.6	-1.2	-1.0	1.3	0.4	-0.8	-1.2	-1.1	-0.3	-5.7
New	10,441	-10.2	-4.9	-11.5	-10.9	-23.6	-16.0	-29.7	-16.3	-3.5	-14.5	-5.7	3.0	13.4	41.1	28.5	45.0	62.4	28.4
nursery	589	4.4	0.5	-0.3	-0.4	-1.3	0.3	10.1	0.8	-0.3	4.8	-3.5	-1.3	-1.8	-2.4	-0.4	-5.2	-1.5	-2.1
paper	1,534	0.6	-3.1	-10.9	-5.0	-9.1	0.9	-7.0	7.3	11.3	-1.2	5.5	-0.4	1.0	2.2	-0.5	-0.6	-0.6	-0.9
park	129	-1.9	-1.1	-1.5	-0.2	-1.1	-2.5	-3.2	0.6	-2.7	9.3	0.6	1.6	7.0	1.1	-1.6	-2.7	-1.0	-0.5
parks	153	-0.6	-0.3	-1.8	-1.2	-2.0	-3.1	-1.8	7.7	-1.1	-1.2	2.1	0.9	14.3	-1.6	-1.1	-1.2	-3.5	-0.2
people	965	-3.8	-8.8	-6.4	-3.3	-12.0	-12.0	-20.3	-4.5	-9.5	-0.3	8.5	2.0	14.1	10.2	18.1	3.3	4.3	2.0
pine	3,683	-25.6	1.1	-9.2	-6.0	-8.7	-2.0	-16.2	-4.2	17.7	18.1	2.0	5.7	-2.3	1.1	1.3	0.5	17.1	-6.8
pines	430	-0.3	2.5	0.6	1.0	0.4	3.2	-1.8	-0.5	9.1	1.5	-1.3	-0.8	-3.1	-3.6	-1.7	-0.4	-1.3	-1.7
Pinus	1,560	-1.3	-1.3	2.6	2.1	-3.8	2.2	2.8	4.9	3.8	2.2	-14.3	0.3	-7.5	-1.3	-2.2	-14.6	6.9	0.7
place	965	3.5	3.2	1.6	2.2	0.5	0.7	3.3	0.4	-2.3	-2.9	-1.1	-1.6	-0.5	-0.5	-0.8	-0.7	-2.7	0.5
planning	820	-7.8	-10.0	-11.7	-4.4	-6.5	-12.3	-6.7	-8.9	0.7	3.9	19.8	17.5	2.7	-0.4	19.0	0.8	-5.9	-1.7
plant	1,100	-2.4	1.0	0.9	-0.8	-0.5	-0.5	2.7	0.9	0.3	-1.6	1.4	0.5	-2.6	1.0	-0.5	-0.5	-0.4	-1.6
Plantation	248	4.3	1.0	0.5	-1.2	0.6	-1.8	0.3	0.4	-1.7	-3.3	-3.4	-2.2	-1.4	1.4	2.5	1.8	1.8	0.6
plantation	999	0.5	-1.0	-4.9	-5.6	-14.7	-14.1	-11.8	-15.4	-11.3	-11.2	-6.5	3.1	-0.4	21.5	25.1	27.0	18.4	15.4
Plantations	115	7.9	1.1	0.8	-0.4	-1.2	-0.5	-1.6	-1.5	-1.2	-2.4	-2.5	-1.8	-0.8	0.4	7.2	2.5	0.3	0.4
plantations	1,093	15.9	0.9	-2.4	-1.6	-2.5	-4.4	-6.9	-5.6	-1.5	-3.4	-3.0	-0.9	-1.2	1.7	2.2	20.2	10.8	4.0
planted	1,772	-0.6	0.8	3.6	1.8	-3.7	1.1	-1.0	-1.3	1.4	0.4	-2.6	-0.9	0.4	-0.9	1.8	-6.7	12.0	-1.0
Planting	203	0.4	-0.4	5.1	0.3	0.4	-0.3	0.4	-1.6	0.4	0.8	0.5	1.1	-0.2	-1.0	-2.4	-1.1	-1.0	-0.3
planting	2,567	-2.2	-0.8	0.6	-2.2	-7.3	-0.9	-4.3	-5.7	-1.6	7.4	4.6	8.2	1.2	0.7	0.7	-1.7	4.1	-1.1
plantings	341	-3.2	-0.8	0.4	-0.6	-1.4	1.2	0.6	-1.9	2.2	0.5	1.0	0.6	2.2	-0.3	-0.3	-1.7	-0.5	-0.4
plants	1,077	-5.8	-0.4	7.5	-0.4	-4.2	0.5	6.9	-0.4	7.5	0.3	-2.1	0.5	2.3	-0.9	-6.7	-3.6	-1.2	-1.1
plot	868	7.2	10.6	-2.1	-0.7	1.9	-0.7	1.8	0.8	-4.3	1.3	-5.0	0.4	-10.5	-4.9	-14.9	-9.7	11.8	7.5
plots	1,466	14.9	9.5	2.8	-0.8	-5.6	0.6	1.6	0.4	-4.0	0.4	-3.7	1.1	-7.1	-7.5	-15.2	-10.4	16.7	6.2

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
podocarp	597	-1.5	-1.8	-1.2	-3.6	5.0	74.7	2.8	-0.8	-11.0	4.6	-1.6	-5.9	-2.1	-3.2	-3.5	-7.2	-8.8	-7.3
podocarps	457	-0.8	2.2	-1.3	-2.6	-1.6	46.8	11.2	3.2	-11.5	0.3	-2.8	-6.1	1.1	-4.0	-7.7	-8.2	-6.1	-5.6
policy	1,072	-3.0	-1.4	-5.7	-4.0	-0.4	-6.3	-5.9	-8.7	-0.8	-1.3	6.3	3.9	3.4	1.0	0.7	0.4	9.7	13.3
population	709	-5.0	-5.1	-1.4	-3.6	-0.8	11.8	2.2	3.7	0.5	-1.3	-0.5	2.6	-4.1	1.1	0.6	-9.2	-2.9	1.2
practical	491	13.1	0.7	-0.5	-1.6	0.3	0.5	0.7	-0.6	0.3	-2.4	-2.3	0.8	-1.3	-0.9	0.7	-0.4	0.4	-0.5
practice	869	1.0	-1.3	0.6	2.0	0.8	4.6	1.1	1.3	-2.1	-0.3	-0.7	0.3	-2.8	-2.6	-1.0	2.2	-3.9	-0.9
problem	950	-0.7	0.6	0.4	-1.1	0.4	1.0	0.5	-0.5	-0.8	-0.6	0.7	0.6	-0.9	1.2	-0.9	0.3	-0.6	1.1
problems	1,135	-1.7	-4.3	-8.0	-2.8	0.9	-0.5	11.2	0.3	-0.8	1.3	1.0	7.7	-0.3	0.5	-0.8	-2.0	-5.4	-2.8
process	857	-1.3	-5.5	-1.2	0.4	-7.7	-1.8	-6.5	-9.0	-3.8	-3.3	3.5	0.4	-0.9	4.9	22.9	21.0	-0.6	4.6
processes	313	-2.2	-3.3	-1.9	0.5	-1.5	2.0	-2.6	-4.3	0.5	-0.5	0.4	1.2	-1.6	0.3	2.9	8.3	1.3	1.0
processing	701	-10.5	-9.8	-12.4	-5.5	-18.6	-19.1	-16.2	-10.2	-2.8	0.7	4.6	2.7	-0.7	21.6	16.7	27.7	0.6	6.5
produce	928	-0.6	-2.3	-0.9	0.9	-2.3	1.1	-1.9	18.8	6.8	-0.6	-0.9	-2.4	1.0	-0.4	-1.7	-3.2	-1.4	-1.4
produced	694	-2.6	-0.3	0.8	1.5	-2.9	0.5	0.6	-1.2	5.4	0.9	-0.7	-0.9	0.7	0.4	0.4	-1.6	-0.7	0.6
producing	261	-1.7	0.5	0.5	-0.5	-0.9	-0.7	-1.8	0.3	2.0	0.3	0.9	-0.3	1.4	0.7	-0.8	0.8	-0.6	-0.3
product	476	-2.1	-2.6	-2.5	-0.3	-3.7	-1.0	-2.1	-1.2	-2.0	-1.6	-1.7	-2.0	-0.4	6.8	1.1	20.1	9.4	1.1
Production	180	-2.7	-1.1	-2.2	-0.4	-2.6	0.4	-1.1	-0.7	-0.5	1.2	3.4	1.5	2.8	0.4	-0.5	-0.4	0.9	-0.6
production	2,358	-18.7	-4.4	-14.8	-1.6	-16.8	-0.5	-8.3	-0.6	1.2	11.4	6.3	4.3	13.5	5.5	-0.3	0.3	0.5	-2.6
productivity	562	-4.6	-5.6	-5.1	-4.4	-14.7	-3.1	-10.2	-10.3	-7.9	14.2	-3.0	7.3	-0.6	5.7	-0.8	0.3	28.1	21.6
Products	588	-6.5	-5.1	-5.4	-1.7	2.6	13.6	7.6	12.9	-0.9	-0.4	-7.2	-3.4	-0.5	-1.8	-2.7	-2.0	-0.8	-0.8
products	1,439	-8.1	-12.1	-17.5	-9.9	-9.3	-10.2	-21.9	-1.7	8.7	1.4	-6.4	-10.9	9.5	27.4	9.1	19.0	10.0	5.6
profession	358	8.0	-0.3	-2.0	2.2	6.2	-1.3	-6.5	-4.2	-7.7	-2.3	-3.1	0.9	2.1	3.2	0.9	8.4	-5.0	0.4
professional	500	1.6	-0.3	-6.4	0.4	1.6	-5.5	-5.8	-7.3	-5.4	-3.4	-1.8	2.5	2.6	3.3	8.5	21.2	-1.1	-0.6
progress	370	2.7	1.1	-0.7	-0.3	1.4	0.5	4.1	0.6	-1.0	0.3	-2.7	-1.4	-0.9	-0.4	0.8	-1.2	-1.5	-1.0
progress	370	2.7	1.1	-0.7	-0.3	1.4	0.5	4.1	0.6	-1.0	0.3	-2.7	-1.4	-0.9	-0.4	0.8	-1.2	-1.5	-1.0
protect	146	-1.4	-1.3	0.4	-0.6	-0.6	-1.7	-1.0	-1.2	-0.5	-0.8	-0.5	0.8	-0.6	2.9	1.8	0.8	3.8	0.9
protected	156	-1.5	0.4	1.0	0.3	-0.3	0.8	0.3	-1.8	-0.7	-1.0	0.3	-1.7	2.0	0.5	-0.4	0.9	2.2	-0.4
Protection	148	0.4	-0.8	0.4	0.3	1.5	0.3	-0.5	-2.4	-1.9	1.0	1.2	-2.0	0.5	0.4	-0.2	-0.2	-0.6	2.5
protection	965	-3.8	0.4	-1.7	-3.3	1.9	-1.1	11.7	-0.3	-3.9	0.9	1.0	-2.8	7.3	1.8	-2.4	-0.6	-2.9	-4.3
pruning	1,129	-9.4	-11.9	0.8	-0.5	-15.0	-13.5	-22.6	137.2	7.2	25.9	-17.8	6.0	-9.3	-1.9	-7.4	-8.0	-9.7	-12.3
public	1,207	-1.7	-6.8	-7.8	-1.1	-3.4	-10.2	-11.4	-7.9	-13.9	2.3	14.8	9.2	17.0	7.2	4.3	3.6	-2.1	-0.4

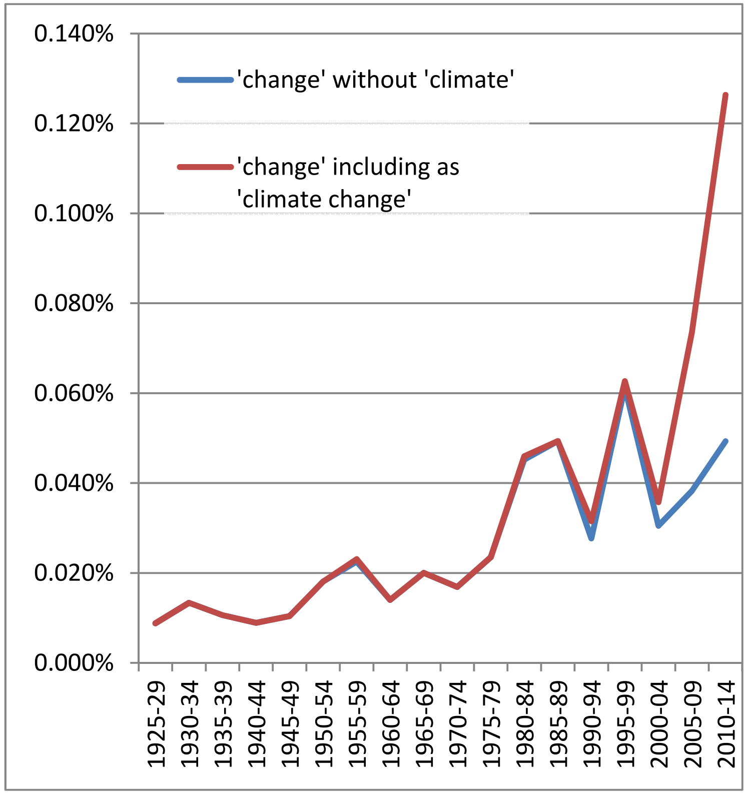
Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
Pulp	210	-3.2	-2.9	-3.7	-1.0	-3.3	0.9	0.7	2.6	5.4	4.8	2.6	-2.3	-1.3	0.3	-1.3	-0.9	-2.3	-1.7
pulp	714	-7.3	-8.6	-8.9	-3.0	-7.3	-0.4	-4.5	2.7	4.3	11.8	27.4	-11.5	0.3	1.9	-1.2	-1.5	-0.6	-4.2
pulping	132	-1.2	-1.8	-2.3	-1.0	-2.1	-0.2	-0.3	0.8	-1.1	4.3	21.1	-2.2	-2.0	-1.8	-2.3	-0.4	-1.0	-0.9
pulps	200	-3.0	-2.8	-3.5	-1.6	-5.8	-0.7	-8.0	-8.6	-0.6	11.2	80.8	-3.2	-2.6	-1.8	-4.9	-3.2	-4.5	-2.4
pulpwood	206	-3.1	-2.0	-3.6	-0.3	-0.7	-2.4	1.2	-0.3	1.0	8.1	6.1	-0.6	3.2	-1.4	-2.5	-3.3	-3.6	-1.1
quality	1,767	-7.6	-9.2	-7.2	-0.5	-8.3	3.9	-7.1	-3.7	0.4	4.3	4.6	1.8	-0.7	-0.8	-0.4	13.3	6.6	0.9
radiata	4,021	-16.0	-6.9	-11.8	-3.5	-48.0	0.3	3.6	0.6	20.3	38.7	-0.9	1.8	-3.8	5.3	-2.4	-7.4	2.5	-0.7
rainfall	608	-1.9	2.9	0.3	-1.8	12.2	-2.1	10.0	0.4	-0.6	-1.9	-2.5	-0.9	0.6	-1.0	0.4	-5.5	-3.4	-0.5
recreation	324	-3.8	-2.1	-5.7	-2.6	-6.0	-8.8	-9.2	3.4	-0.9	12.4	9.3	2.0	13.0	-2.1	-1.3	-5.6	-1.5	-0.5
recreational	249	-3.7	-2.5	-4.4	-1.2	-3.5	-2.7	-2.5	1.5	0.4	4.6	9.3	1.4	7.0	-0.3	-1.2	-5.2	-1.5	-1.1
recreational	249	-3.7	-2.5	-4.4	-1.2	-3.5	-2.7	-2.5	1.5	0.4	4.6	9.3	1.4	7.0	-0.3	-1.2	-5.2	-1.5	-1.1
regeneration	1,273	-2.8	4.0	2.8	24.0	2.3	44.8	3.4	1.4	-1.3	1.2	-0.7	-6.7	-5.8	-13.8	-12.8	-16.9	-17.8	-8.3
research	1,806	-2.1	-5.3	-17.2	-4.5	-6.4	-8.0	1.5	-6.9	-8.2	-0.3	0.9	-0.8	1.3	44.9	19.6	0.4	0.5	8.5
Research	2,072	-19.0	-14.9	-10.4	-11.4	-15.0	7.7	1.6	5.2	-3.5	1.9	-6.2	-2.3	1.1	5.9	19.9	1.3	4.5	-1.0
reserve	121	0.9	2.8	1.6	-0.2	-1.0	-0.4	-1.1	0.5	-1.3	1.2	0.9	0.7	-0.4	-0.5	-1.0	-1.2	-1.9	0.4
Reserves	126	1.5	-0.6	2.8	1.1	0.4	2.8	0.5	0.9	-2.6	1.9	-0.8	-0.6	-0.9	-0.8	-3.1	-1.8	-2.0	-0.5
reserves	289	-0.5	0.9	0.3	-0.4	0.4	-1.8	-2.1	1.0	-1.4	5.8	2.8	0.4	1.7	-1.1	-2.9	-0.5	-3.7	-0.5
Resource	176	-2.6	-2.5	-3.1	-1.4	-5.1	-2.9	-4.0	-6.3	-3.1	-5.2	-3.7	-1.0	1.3	5.7	56.3	2.0	0.3	1.6
resource	737	-11.1	-6.9	-10.3	-5.8	-18.2	-8.5	-13.0	-11.2	-1.6	1.7	8.3	4.6	4.9	10.9	21.7	2.5	0.7	2.2
Resources	135	-2.0	-1.9	-0.7	-0.5	0.4	-0.8	-1.1	-2.0	-1.2	-0.9	-0.5	2.4	0.6	0.6	2.1	4.7	1.1	0.3
resources	799	-5.5	-8.6	-8.5	-2.4	-3.0	-1.5	-2.3	0.5	-0.7	2.0	7.2	4.3	2.9	1.2	1.5	-2.0	0.3	2.0
rimu	1,153	38.2	24.6	1.4	-1.3	-5.0	42.3	8.4	1.4	-10.7	-6.0	7.1	-22.7	-3.1	-11.8	-20.2	-17.5	-24.3	-12.6
root	868	-0.6	-0.7	-1.0	-1.3	-4.1	-6.1	0.9	7.4	37.2	1.4	-8.5	0.5	-9.1	-7.9	7.0	-4.9	-0.3	-7.2
rotation	709	-5.0	-1.4	-4.7	-0.6	-1.9	1.0	-7.6	1.4	-1.0	1.2	-1.8	0.5	-2.0	0.3	1.9	4.6	12.4	1.6
rotations	229	-3.4	-2.3	-4.0	-0.4	-3.1	-1.5	-2.5	-1.6	-0.7	5.1	0.3	1.7	0.8	-0.4	-1.2	6.8	2.8	2.3
roundwood	128	-1.9	-1.8	-2.3	-1.0	-3.7	-3.5	-3.2	0.4	8.8	-0.5	-1.8	0.3	4.2	1.8	-0.2	0.8	3.6	-1.6
sand	436	-2.1	2.4	4.4	2.6	-5.9	-1.3	-5.1	-4.3	130.4	-1.2	-6.3	-2.9	-5.5	-5.6	-5.7	-6.8	-1.6	-2.7
sawing	179	0.6	-1.1	-1.6	1.4	-1.3	0.5	1.4	4.2	0.5	2.3	-0.4	-0.8	-1.7	-0.5	-3.3	0.3	-2.3	-0.4
sawlog	232	-3.5	-3.2	-4.1	-1.8	-5.5	-5.1	-5.9	0.4	0.8	3.9	1.2	1.0	7.2	0.6	-3.7	13.1	0.3	-2.8
sawlogs	237	-3.6	-3.3	-4.2	-1.9	-4.7	-0.4	-0.8	1.6	3.2	3.7	-1.4	0.8	5.1	0.5	-2.5	1.2	-0.8	-0.3

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
sawmill	223	0.5	-1.1	6.5	1.3	-3.0	0.9	-0.5	0.8	0.5	0.5	-3.3	0.3	-1.9	1.5	0.5	0.6	-3.9	-0.4
sawmilling	165	-1.6	-0.4	0.9	-0.7	-1.4	-0.2	-1.1	-1.1	-1.0	5.5	1.1	1.6	-0.2	0.6	-0.2	0.3	-3.7	0.3
sawmills	177	-1.2	-1.1	-0.5	-1.4	-0.7	-0.4	-4.8	-2.3	2.7	10.3	-0.3	-2.1	-0.3	2.9	1.7	-0.3	-1.7	0.3
sawn	577	-1.4	-1.1	-1.3	-0.4	-2.1	-0.3	-1.5	3.5	2.7	1.4	4.6	-3.5	0.9	0.7	-4.0	-1.2	0.8	-0.9
science	405	1.4	-0.8	-2.5	-3.2	1.3	-4.2	-4.3	-5.5	-8.0	-6.4	0.3	-1.0	0.3	34.3	3.8	1.3	0.6	5.3
Science	451	-1.9	-2.9	-1.8	-1.4	-2.0	0.3	-2.4	-3.3	-8.2	-4.2	-6.2	-1.0	5.4	10.6	7.0	1.4	14.2	4.1
Scientific	154	-2.3	-0.6	2.4	0.3	0.7	0.6	0.7	2.6	-3.3	-0.5	-1.0	0.3	1.4	0.4	-1.6	-0.6	-0.7	-0.7
scientific	369	1.5	1.3	-0.4	-1.4	0.6	-1.2	-2.5	-2.7	-2.9	2.2	3.9	-1.0	2.8	0.7	-2.1	-0.5	0.7	0.5
scientists	165	-1.6	-1.5	-0.7	-1.3	-2.9	-2.7	-2.5	-0.9	-1.3	5.5	2.3	0.7	0.7	2.8	0.4	0.8	0.3	0.5
scrub	573	-0.9	2.5	-1.1	-0.3	-0.7	26.6	18.9	-0.7	-0.6	-2.3	-1.5	-2.1	0.4	-2.2	-3.9	-8.4	-4.5	-5.8
seed	2,240	-0.4	0.7	2.9	4.9	1.4	27.1	3.0	1.8	-7.7	11.6	-8.4	2.7	-2.6	-1.0	-14.3	-36.5	-2.5	-19.4
seedlings	1,906	-2.6	-0.7	-5.2	-0.4	-10.4	-0.7	15.9	4.8	1.8	29.4	-7.2	7.3	3.8	-6.3	-12.6	-26.9	-0.7	-14.8
Service	4,387	-7.1	-9.3	1.1	-1.8	1.2	77.2	1.5	6.5	3.0	39.3	-8.7	-6.7	14.4	-16.8	-25.1	-27.4	-50.9	-11.3
silvicultural	796	0.6	-4.3	-1.8	-0.5	0.9	15.6	1.3	0.4	-0.3	-0.4	-1.3	2.6	-1.5	-1.4	-2.2	-1.4	-0.7	-2.9
Silviculture	133	4.3	-0.7	-0.7	-1.0	0.8	0.7	-1.3	0.3	-1.6	0.9	-1.5	0.3	1.5	0.6	-1.2	1.0	-0.7	-0.6
silviculture	472	1.5	-2.6	-1.7	-0.8	0.5	1.2	1.1	-0.5	-0.7	-0.9	-0.4	4.1	-1.6	0.6	1.5	-0.4	-1.1	-1.3
slopes	693	-4.8	3.0	-0.4	0.7	1.1	2.0	13.2	-2.1	3.3	0.3	-1.3	-1.8	-0.3	-0.5	0.7	-9.8	-4.5	-7.2
softwood	215	-3.2	-3.0	-0.4	-1.7	-1.9	-1.0	1.6	0.3	5.2	1.2	-2.2	-0.6	4.1	-0.3	-0.6	-0.4	0.3	0.4
softwoods	208	-0.8	-0.7	-0.8	-1.0	-0.9	1.1	3.8	-1.2	2.1	1.3	1.2	-1.9	-1.7	-0.4	-1.6	-2.0	-1.3	4.1
Soil	657	-9.9	-3.0	-5.1	0.5	0.3	-2.0	0.8	-0.7	-1.7	2.7	-0.9	16.8	9.7	-1.1	-0.8	-6.8	1.0	-1.9
soil	2,827	-3.4	1.7	4.4	5.5	1.1	0.8	5.8	3.8	-1.2	7.1	-5.1	1.1	-1.5	-1.6	-9.3	-19.4	-0.7	-5.5
soils	1,555	-20.2	-6.7	-2.6	-5.7	-4.1	29.7	8.6	4.8	2.7	4.6	-1.3	3.8	4.1	-5.4	-11.0	-20.4	-5.1	-6.8
species	6,570	-3.9	-0.5	20.7	1.0	18.5	56.9	37.2	-0.6	-34.8	-10.2	-10.9	-1.6	-4.5	-8.2	-25.3	-20.2	4.9	-0.3
stand	2,169	3.9	0.9	-3.6	-1.6	-10.2	1.4	-1.9	11.1	32.2	-2.9	-1.2	0.4	-2.0	-17.1	-4.1	1.3	1.2	-3.4
state	515	1.7	-0.6	-0.3	-0.5	0.6	0.8	-1.4	-2.0	-0.9	-1.7	-0.8	-0.3	0.9	-0.3	0.7	0.4	-0.3	10.0
State	2,547	1.3	2.4	77.9	9.4	40.9	-2.2	-7.1	-15.6	-7.3	-1.0	2.3	0.3	5.9	-3.1	-3.8	-19.5	-28.7	-12.8
stems	975	-13.1	-3.3	-5.5	-0.8	-13.5	11.8	1.0	23.0	-0.6	15.4	-0.4	-0.4	-0.3	-11.0	-8.6	-4.7	-0.8	-0.9
stock	896	-0.6	-0.8	1.3	-0.3	-0.8	-3.3	0.6	-5.3	0.8	15.1	-10.5	9.5	1.5	-0.6	-0.5	-2.4	0.7	-4.7
stocking	906	0.7	-0.8	-2.6	-1.4	-1.4	5.9	0.6	4.0	2.8	3.4	-2.2	-0.4	-4.4	-5.0	-13.9	-3.6	13.7	-3.8
study	1,609	1.8	6.8	-11.3	-2.8	-5.7	-0.7	-4.6	-0.5	3.6	1.4	1.0	3.4	-1.6	-4.0	8.5	-5.9	4.0	-1.1

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
sustainability	135	-2.0	-1.9	-2.4	-1.1	-3.9	-3.7	-5.4	-5.8	-3.8	-4.9	-5.0	-3.0	-1.5	16.4	7.0	16.0	4.8	6.6
sustainable	448	-6.7	-6.3	-7.9	-3.5	-13.0	-12.2	-17.8	-19.2	-12.8	-16.4	-10.7	-5.9	-5.7	32.9	41.9	49.9	3.9	29.6
sustained	353	-5.3	-2.4	-1.2	-1.3	1.1	1.8	1.2	-1.5	-1.2	-0.3	1.6	0.3	9.5	3.3	-1.3	-3.2	-2.6	-1.1
system	1,435	-1.1	0.4	-7.2	-0.6	-10.4	-4.4	-5.0	-5.0	8.6	-2.2	0.4	37.4	1.1	-2.2	13.2	-0.3	0.4	-3.5
Tasmania	122	-0.2	1.4	1.3	-0.5	3.1	-1.7	-2.3	-4.1	0.4	-3.4	3.0	-2.7	11.1	0.3	-1.5	-0.5	-1.3	-0.5
Technical	186	-2.8	-0.8	-2.3	-0.2	12.7	0.8	0.3	0.7	-3.3	-1.0	-4.0	0.3	-0.3	0.5	-0.3	1.2	-0.6	-0.2
technical	482	1.6	-1.0	-2.5	1.5	1.1	-1.6	-1.4	-0.3	-3.0	-0.3	-1.8	-0.7	4.0	0.8	2.4	0.7	0.6	0.6
techniques	549	-8.2	-7.7	-9.7	-4.3	-6.6	-2.4	1.8	2.9	0.3	1.6	4.4	1.3	-0.6	1.9	4.2	-0.9	-0.8	-0.4
Technology	144	0.7	-1.3	0.3	-1.1	-1.4	-0.5	-1.6	-5.0	-4.1	-4.1	-4.2	-2.5	0.5	2.6	17.9	2.1	3.0	3.1
technology	272	-1.4	-1.6	-4.8	-2.1	-5.6	-7.4	-8.3	-7.2	-5.5	-1.0	1.0	0.7	1.1	10.6	9.2	6.1	2.5	7.8
thinning	1,602	-6.4	-2.0	-13.0	-1.9	-2.5	15.6	-6.3	67.2	17.1	6.0	-0.6	-6.0	-5.4	-11.1	-3.0	-8.6	-9.3	-5.8
Timber	653	-6.4	-2.2	5.3	12.1	-0.3	1.2	0.6	0.8	4.5	-0.6	-8.8	-2.4	1.0	-0.9	-2.1	1.4	-4.0	0.7
timber	4,754	0.4	1.6	122.8	1.4	1.4	12.3	-5.7	1.6	2.3	-6.6	1.7	-25.4	0.4	-6.9	-12.1	-10.8	-7.0	-3.2
timbers	494	3.6	1.3	0.4	1.7	0.7	1.0	11.6	-6.6	-1.3	-4.3	12.7	-4.3	-0.7	-5.2	-5.0	-3.3	0.4	-3.3
trade	533	-4.2	1.4	0.3	-1.4	-2.9	-1.1	-1.7	-3.0	34.5	-1.1	-2.5	-10.0	1.2	0.3	-1.6	-0.3	11.7	-0.6
trained	157	1.4	0.9	-0.6	-0.6	3.3	-0.6	-1.9	-0.3	-1.6	0.4	-1.3	1.0	4.0	-1.2	-0.3	-0.6	-0.7	-0.3
Training	174	-2.6	-1.6	-2.2	-1.4	1.5	0.4	-0.6	8.5	-3.0	-1.0	-3.6	-1.6	2.6	-0.5	1.8	0.7	-3.9	4.5
training	387	-0.3	-0.3	-5.6	-0.3	4.0	-1.0	-0.7	-4.2	-4.7	0.4	-3.7	0.9	8.6	0.5	2.0	1.3	-1.9	3.6
training	387	-0.3	-0.3	-5.6	-0.3	4.0	-1.0	-0.7	-4.2	-4.7	0.4	-3.7	0.9	8.6	0.5	2.0	1.3	-1.9	3.6
transport	285	1.4	-0.7	-0.3	-0.2	-2.7	-0.4	-0.9	-3.1	0.8	1.1	1.2	2.0	-2.4	0.6	2.6	-0.9	-0.3	-0.3
tree	3,643	0.4	3.7	1.1	-0.9	8.9	0.4	3.2	-4.1	0.6	-0.5	-8.5	-1.4	-3.2	-0.4	-1.4	-1.0	3.8	0.9
trees	7,451	4.4	45.2	13.9	10.1	3.2	4.1	2.1	2.3	5.4	0.7	-15.1	-6.6	-9.1	-5.0	-4.4	-13.0	-26.0	-6.1
undergrowth	110	-1.7	8.7	0.8	-0.4	11.8	0.9	0.8	0.3	0.8	-1.3	-3.1	-1.7	-2.4	-2.2	-1.8	-2.3	-2.5	-1.3
University	963	-0.8	0.9	-3.8	-0.9	-0.5	-3.8	-13.3	-4.5	-3.9	-2.7	-10.8	4.0	2.2	3.2	20.7	9.5	5.5	2.5
values	1,070	-10.2	1.3	-4.5	-6.1	-11.9	-8.7	-11.0	-1.7	-3.7	0.3	1.7	1.4	5.9	0.3	7.3	4.1	21.5	5.4
vegetation	988	-6.4	-1.1	1.4	0.6	-1.8	3.2	27.2	1.6	-0.4	0.7	-2.2	-0.9	-1.7	-1.8	-4.4	-5.6	-2.3	0.6
virgin	259	7.0	1.4	2.1	-0.8	2.0	3.9	0.7	0.4	-3.7	-1.0	-0.4	-0.5	1.5	-2.7	-6.4	-3.5	-4.7	-0.8
wilderness	143	-1.4	-2.0	-1.1	-1.1	-3.1	-2.9	-4.5	-3.3	-4.1	-2.1	27.0	30.0	0.4	-2.9	-2.6	-2.1	-1.7	-1.8
Wood	490	6.7	-1.9	-1.9	-0.7	-2.9	-1.7	-6.5	-4.2	-3.1	-0.9	-1.9	0.4	1.9	0.7	-0.4	9.6	5.2	14.2
wood	3,509	7.9	-9.8	-14.0	-5.3	-7.0	-15.0	-33.9	-26.1	-1.7	3.5	0.4	1.1	2.8	16.2	1.2	30.1	9.5	41.5

Word	No.	1925-29	1930-34	1935-39	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14
woods	189	29.2	0.8	-0.6	7.9	1.4	3.3	-5.3	-2.2	-2.7	-1.0	-0.3	-1.9	-0.4	-1.2	-2.8	-2.2	-1.9	-1.0
workers	281	-0.6	-0.5	-0.7	-0.9	-1.3	-1.4	0.3	-0.3	-1.3	-0.3	-2.2	16.3	2.1	-3.7	0.4	0.9	-2.0	0.8
world	875	-1.2	-6.3	-0.7	-2.3	-0.5	-6.2	-16.0	-3.3	-1.0	0.9	0.5	-1.4	3.4	9.2	-1.0	12.5	3.2	12.1
Zealand	9,513	-9.1	-4.3	-13.1	-9.5	-26.0	-15.9	-26.2	-16.6	-3.7	-13.1	-4.7	2.4	14.2	39.8	15.1	45.0	71.2	32.4

word	***change***	***climate change***	***change* without *climate***	Total words in period	percentage of total words that are change (without 'climate')	percentage of total words that are change (without 'climate')
Total	1224	182	1042	4,063,681	0.026%	0.030%
1925-29	12	0	12	136,304	0.009%	0.009%
1930-34	17	0	17	127,326	0.013%	0.013%
1935-39	17	0	17	160,358	0.011%	0.011%
1940-44	9	0	9	101,210	0.009%	0.009%
1945-49	28	0	28	269,504	0.010%	0.010%
1950-54	44	0	44	243,348	0.018%	0.018%
1955-59	81	2	79	351,047	0.023%	0.023%
1960-64	53	0	53	378,250	0.014%	0.014%
1965-69	51	0	51	254,621	0.020%	0.020%
1970-74	55	0	55	325,417	0.017%	0.017%
1975-79	79	0	79	336,186	0.023%	0.023%
1980-84	123	2	121	267,624	0.045%	0.046%
1985-89	99	0	99	200,629	0.049%	0.049%
1990-94	58	7	51	184,260	0.028%	0.031%
1995-99	139	3	136	221,862	0.061%	0.063%
2000-04	68	10	58	190,255	0.030%	0.036%
2005-09	150	72	78	203,886	0.038%	0.074%
2010-14	141	86	55	111,594	0.049%	0.126%



Appendix D. Plantation wood production data.

National totals for Australia and Indonesia were taken from FAOSTAT (2015). Australian plantation wood data was sourced from ABARES data.

Indonesian plantation data is based on various Ministry for Forestry annual statistical reports for *hutan tanaman industri* (industrial plantation) and *Perum Perhutani* (a Java based government owned plantation company). Years before 1997 are extrapolated based on assumed low level production from plantations mainly on Java and 2014 data is duplicated from 2015 data. The data does not include other sources of smallholder cultivated wood which would increase the portion represented as plantation. National Indonesian wood production data is likely to contain errors due to reporting issues including those associated with illegal logging (see for example Harwell 2009; Tacconi 2012).

New Zealand data is for plantation and natural forest sources (Ministry of Primary Industries 2015) and the total was derived by adding plantation and natural forest sources.

1000 m3 / year	Australia Industrial roundwood	Australia Natural forest	Australia Plantation	New Zealand Industrial roundwood	New Zealand Natural forest	New Zealand Plantation	Indonesia Industrial roundwood	Indonesia Natural forest	Indonesia Plantation	Total Industrial roundwood	Total Natural forest	Total Plantation
1961	10,738	8,761	1,977	4,769	1,557	3,212	5,540	5,040	500	21,047	15,358	5,689
1962	10,061	8,010	2,051	4,952	1,531	3,421	5,653	5,059	594	20,666	14,600	6,066
1963	10,573	8,448	2,125	4,655	1,316	3,339	5,687	5,045	642	20,915	14,809	6,106
1964	11,272	9,072	2,200	5,156	1,330	3,826	5,802	5,113	689	22,230	15,515	6,715
1965	11,294	9,020	2,274	5,693	1,302	4,391	5,889	5,153	736	22,876	15,475	7,401
1966	11,614	9,265	2,349	5,858	1,234	4,624	6,115	5,332	783	23,587	15,831	7,756
1967	11,328	8,905	2,423	6,016	1,223	4,793	6,658	5,827	831	24,002	15,955	8,047
1968	11,426	8,948	2,478	6,297	1,070	5,227	7,384	6,506	878	25,107	16,524	8,583
1969	11,265	8,681	2,584	6,885	979	5,906	8,921	7,996	925	27,071	17,656	9,415
1970	11,196	8,541	2,655	7,820	1,042	6,778	12,666	11,694	972	31,682	21,277	10,405
1971	11,812	9,017	2,795	8,205	1,029	7,176	15,747	14,728	1,019	35,764	24,774	10,990
1972	11,362	8,449	2,913	7,972	958	7,014	18,920	17,853	1,067	38,254	27,260	10,994
1973	11,311	8,263	3,048	8,250	899	7,351	28,346	27,232	1,114	47,907	36,394	11,513
1974	11,591	8,715	2,876	8,585	925	7,660	25,297	24,136	1,161	45,473	33,776	11,697
1975	13,192	10,102	3,090	8,361	964	7,397	18,330	17,122	1,208	39,883	28,188	11,695
1976	12,872	9,755	3,117	8,272	928	7,344	26,066	24,810	1,256	47,210	35,493	11,717
1977	13,889	10,571	3,318	9,701	808	8,893	25,420	24,117	1,303	49,010	35,496	13,514
1978	14,069	10,547	3,522	9,243	669	8,574	29,908	28,558	1,350	53,220	39,774	13,446
1979	13,696	10,075	3,621	8,974	583	8,391	28,247	26,850	1,397	50,917	37,508	13,409
1980	15,651	11,545	4,106	9,911	539	9,372	30,922	29,477	1,444	56,484	41,561	14,922
1981	15,928	11,241	4,687	10,245	551	9,694	26,527	25,035	1,492	52,700	36,827	15,873
1982	14,872	10,108	4,764	9,753	514	9,239	25,523	23,984	1,539	50,148	34,606	15,542

1000 m3 / year	Australia Industrial roundwood	Australia Natural forest	Australia Plantation	New Zealand Industrial roundwood	New Zealand Natural forest	New Zealand Plantation	Indonesia Industrial roundwood	Indonesia Natural forest	Indonesia Plantation	Total Industrial roundwood	Total Natural forest	Total Plantation
1983	13,787	9,105	4,682	9,358	608	8,750	28,731	27,144	1,586	51,876	36,857	15,018
1984	15,076	10,147	4,929	9,266	599	8,667	30,466	28,832	1,633	54,808	39,578	15,229
1985	16,829	10,821	6,008	9,626	675	8,951	27,170	25,489	1,681	53,625	36,985	16,640
1986	17,119	10,921	6,198	10,195	643	9,552	31,141	29,413	1,728	58,455	40,977	17,478
1987	16,746	10,990	5,756	9,613	563	9,050	34,914	33,139	1,775	61,273	44,692	16,581
1988	16,902	10,976	5,926	9,688	570	9,118	38,546	36,723	1,822	65,136	48,269	16,866
1989	16,584	10,191	6,393	10,619	377	10,242	41,778	39,908	1,869	68,981	50,476	18,504
1990	17,213	9,943	7,270	11,486	357	11,129	38,366	36,449	1,917	67,065	46,749	20,316
1991	16,604	9,811	6,793	13,454	361	13,093	41,991	40,027	1,964	72,049	50,199	21,850
1992	16,654	9,273	7,381	13,903	205	13,698	43,108	41,096	2,011	73,665	50,574	23,090
1993	17,659	9,553	8,106	14,690	206	14,484	44,083	42,024	2,058	76,432	51,783	24,648
1994	18,762	9,553	9,209	14,871	204	14,667	42,617	40,511	2,106	76,250	50,268	25,982
1995	19,560	10,617	8,943	16,183	205	15,978	43,203	41,050	2,153	78,946	51,872	27,074
1996	19,340	9,795	9,545	16,692	130	16,562	47,242	45,042	2,200	83,274	54,967	28,307
1997	19,791	8,760	11,031	16,074	110	15,964	47,991	45,559	2,431	83,856	54,429	29,426
1998	21,158	9,696	11,462	16,705	75	16,630	53,119	50,956	2,163	90,982	60,727	30,254
1999	20,838	9,060	11,778	15,814	125	15,689	53,349	50,562	2,786	90,001	59,748	30,253
2000	24,407	10,853	13,554	18,196	76	18,120	48,849	43,554	5,295	91,452	54,483	36,968
2001	24,392	10,480	13,912	19,287	55	19,232	44,449	37,426	7,023	88,128	47,961	40,167
2002	24,192	9,484	14,708	20,940	57	20,883	52,349	46,547	5,802	97,481	56,088	41,393
2003	25,714	9,969	15,745	22,472	39	22,434	51,849	45,546	6,303	100,035	55,554	44,481
2004	26,332	9,684	16,648	20,911	32	20,878	51,849	43,596	8,253	99,091	53,313	45,779
2005	26,332	8,960	17,372	19,334	26	19,308	50,072	40,153	9,919	95,737	49,139	46,598
2006	26,735	8,337	18,398	18,894	23	18,871	47,451	25,440	22,010	93,080	33,800	59,280
2007	27,083	8,201	18,882	19,974	18	19,956	47,451	26,788	20,662	94,507	35,008	59,499

1000 m3 / year	Australia Industrial roundwood	Australia Natural forest	Australia Plantation	New Zealand Industrial roundwood	New Zealand Natural forest	New Zealand Plantation	Indonesia Industrial roundwood	Indonesia Natural forest	Indonesia Plantation	Total Industrial roundwood	Total Natural forest	Total Plantation
2008	28,210	8,543	19,667	20,481	18	20,462	54,304	31,887	22,416	102,994	40,448	62,546
2009	25,488	7,188	18,300	18,937	16	18,920	47,806	28,764	19,042	92,230	35,969	56,262
2010	25,561	6,348	19,213	22,042	14	22,028	54,106	35,451	18,654	101,709	41,814	59,895
2011	26,532	6,087	20,445	25,131	17	25,114	60,706	40,752	19,954	112,368	46,856	65,513
2012	23,497	4,250	19,247	26,070	16	26,053	62,606	36,336	26,269	112,172	40,603	71,570
2013	22,579	3,522	19,057	28,164	15	28,149	62,606	27,143	35,463	113,348	30,680	82,668
2014	25,299	3,790	21,509	30,258	24	30,235	62,606	33,158	29,447	118,163	36,972	81,191
2015	27,335	3,875	23,460	29,602	21	29,581	62,606	33,158	29,447	119,542	37,054	82,488

Appendix E. Data for Chapter 5

The data in this appendix is based on the supplementary materials for the paper, 'Global wood production from natural forests has peaked', published in *Biodiversity Conservation* (Warman 2014). The data was updated to reflect an extra three years FAO data that had become available since the paper was written in 2013. Copyright for this material rests with the publisher, Springer.

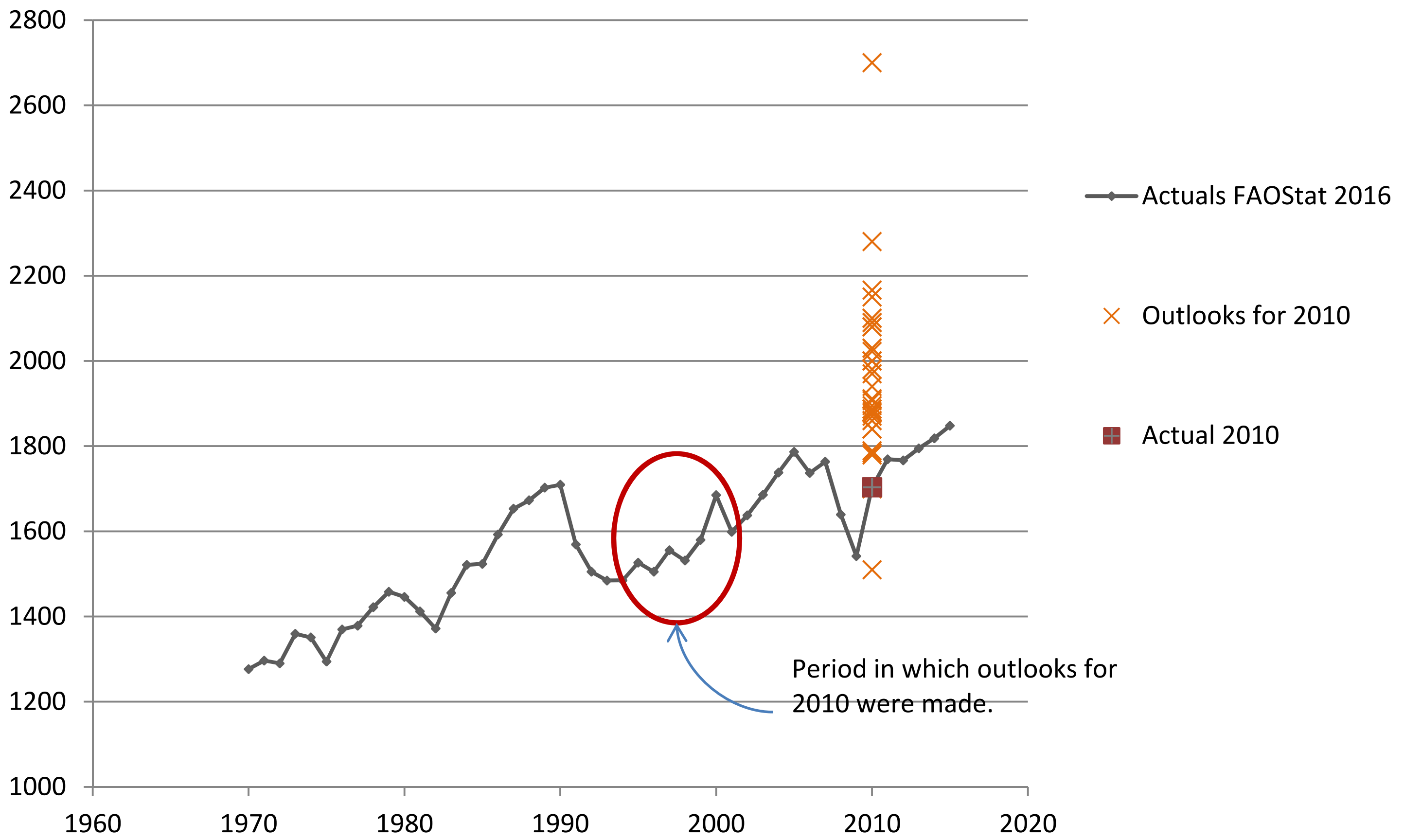
Modelled outlooks for world industrial roundwood for year 2010 – between 1994 and 2010

Source	000,000m3	Method notes
Actual reported by FAO for 2010	1,703	
Mean of selected predictions 1994 - 2001	1,961	
Median of selected predictions 1994 - 2001	1,940	
From ***Smeets et al 2007***		
Alexandratos (1994)	2,700	n/d
Apsey and Reed (1995) demand	1,940	The demand is assumed to increase at 1.5% per year; N/a.
Apsey and Reed (1995) supply	1,510	The supply is estimated based on "judgemental extrapolation from region and country data and a network of experts".
Brooks et al., (1996) low GDP, high price	1,840	The consumption of industrial roundwood per capita is
Brooks et al., (1996) high GDP, high price	1,860	modelled as a function of income per capita and prices. Price
Brooks et al., (1996) low GDP, medium price	1,980	and income elasticities are derived from historic data.
Brooks et al., (1996) high GDP, medium price	2,000	
Brooks et al., (1996) low GDP, stable price	2,080	

Source	000,000m3	Method notes
Brooks et al., (1996) high GDP, stable price	2,090	
Brooks et al., (1996) constant per capita consumption	2,030	
FAO 1995 in FAO (1997a)	2,280	
FAO (1997b) 1475 1627 1784	1,784	The Global Forests Product Model (GFPM) (Buongiorno et al., 2003) is a dynamic economical equilibrium model that predicts production, consumption, trade and prices of 14 forest products in 180 countries.
FAO (1999)	1,870	GFPM, see (FAO, 1997b).
FAO (2003, unpublished data) GFPM model runs to	1,887	GFPM, see (Buongiorno et al., 2003)
IIED (1996)	1,887	N/a
IMAGE-team (2001) A1 scenario	2,022	Consumption is modelled as a function of population growth,
IMAGE-team (2001) A2 scenario	1,877	industrial value added, the availability of forests, prices and
IMAGE-team (2001) B1 scenario	1,779	wood demand. Correlations are statistically derived from
IMAGE-team (2001) B2 scenario	1,911	historic data.
ITTO (1999)	2,166	N/a
Nilsson (1996), demand	2,100	Methods are similar to those used by Apsey and Reed (1995)
Nilsson (1996), non-mainstream demand	1,895	Methods are similar to those used by Apsey and Reed (1995)
Poyry, 1995 in FAO (1997a)	1,700	Economical demand and supply modelling, includes population growth and economic growth; n/d
Whiteman (1999) 1493 1881 GFPM, see (Buongiorno et al., 2003)	1,881	GFPM, see (Buongiorno et al., 2003)
WRI (1998) 1907 2251 N/a	1,907	N/a
Constant per capita consumption Based on population pro	1,789	Based on population projections of the United Nations (UNPD, 2003) and historic data.
From ***ABARE 1999***		
Jaakko Pyroy 1995	1,700	
Sedjo and Lyon 1996	2,100	

Source	000,000m3	Method notes
Sedjo and Lyon 1995	1,970	
Simons (1994)	2,150	
Solberg (1996) 1	1,840	
Solberg (1996) 2	1,860	
Solberg (1996) 3	1,980	
Solberg (1996) 4	2,000	
Solberg (1996) 5	2,080	
Solberg (1996) 6	2,090	
Solberg (1996) 7	2,030	
Fuelwood	000,000m3	
From ***Smeets et al 2007***	2,030	
Brooks et al., (1996) low GDP growth	2,030	
Brooks et al., (1996) high GDP growth	1,880	
Brooks et al., (1996) constant per capita consumption	3,020	
FAO (2003, unpublished data) GFPM model runs to	2,585	
IMAGE-team (2001) A1 scenario	2,065	
IMAGE-team (2001) A2 scenario	2,416	
IMAGE-team (2001) B1 scenario	1,937	
IMAGE-team (2001) B2 scenario	1,941	

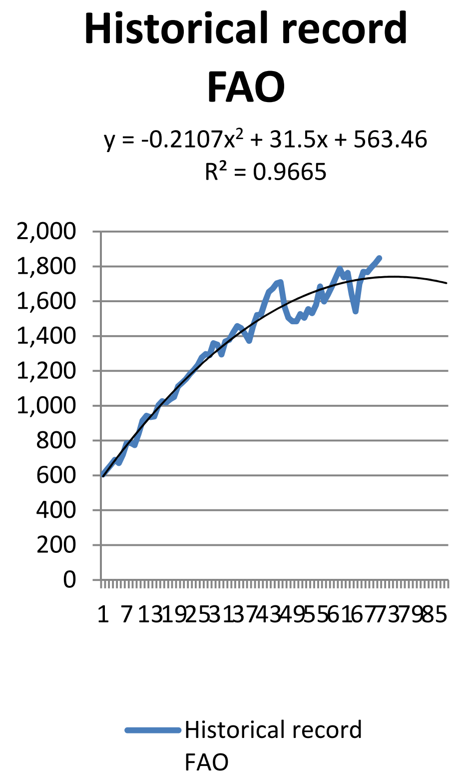
Graph of above results



World industrial roundwood data and models

million m3 / year	FAOSTAT 2016	FAO *yearbook of forest products* 1962	FAO *yearbook of forest products* 1958	FAO yearbooks combined	Annual decrease by average annual decline of 1948-1960	Complete historical data	Historical record FAO	Trend estimate of historical record ($y = -0.2107x^2 + 31.5x + 563.46$	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
1945					605	605	605	650			
1946					633	633	633	681			
1947					662	662	662	712			
1948			690	690		690	690	743			
1949			671	671		671	671	773			
1950			719	719		719	719	802			
1951			784	784		784	784	831			
1952		787		787		787	787	860			
1953		774		774		774	774	889			
1954		839		839		839	839	916			
1955		914		914		914	914	944			
1956		943		943		943	943	971			
1957		935		935		935	935	998			
1958		938		938		938	938	1,024			
1959		1,002		1,002		1,002	1,002	1,050			
1960		1,026		1,026		1,026	1,026	1,075			
1961	1,018	1,022				1,018	1,018	1,100			
1962	1,036					1,036	1,036	1,125			
1963	1,050					1,050	1,050	1,149			

million m3 / year	FAOSTAT 2016	FAO *yearbook of forest products* 1962	FAO *yearbook of forest products* 1958	FAO yearbooks combined	Annual decrease by average annual decline of 1948-1960	Complete historical data	Historical record FAO	Trend estimate of historical record (y = -0.2107x² + 31.5x + 563.46	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
1964	1,111					1,111	1,111	1,172			
1965	1,132					1,132	1,132	1,196			
1966	1,153					1,153	1,153	1,219			
1967	1,182					1,182	1,182	1,241			
1968	1,206					1,206	1,206	1,263			
1969	1,234					1,234	1,234	1,285			
1970	1,276					1,276	1,276	1,306			
1971	1,296					1,296	1,296	1,327			
1972	1,290					1,290	1,290	1,347			
1973	1,359					1,359	1,359	1,367			
1974	1,351					1,351	1,351	1,386			
1975	1,294					1,294	1,294	1,405			
1976	1,370					1,370	1,370	1,424			
1977	1,378					1,378	1,378	1,442			
1978	1,422					1,422	1,422	1,460			
1979	1,458					1,458	1,458	1,477			
1980	1,446					1,446	1,446	1,494			
1981	1,412					1,412	1,412	1,511			
1982	1,372					1,372	1,372	1,527			
1983	1,455					1,455	1,455	1,543			
1984	1,521					1,521	1,521	1,558			
1985	1,523					1,523	1,523	1,573			
1986	1,592					1,592	1,592	1,587			



million m3 / year	FAOSTAT 2016	FAO *yearbook of forest products* 1962	FAO *yearbook of forest products* 1958	FAO yearbooks combined	Annual decrease by average annual decline of 1948-1960	Complete historical data	Historical record FAO	Trend estimate of historical record (y = -0.2107x² + 31.5x + 563.46	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
1987	1,653					1,653	1,653	1,601			
1988	1,673					1,673	1,673	1,615			
1989	1,702					1,702	1,702	1,628			
1990	1,709					1,709	1,709	1,641			
1991	1,569					1,569	1,569	1,653			
1992	1,505					1,505	1,505	1,665			
1993	1,484					1,484	1,484	1,677			
1994	1,485					1,485	1,485	1,688			
1995	1,526					1,526	1,526	1,698			
1996	1,505					1,505	1,505	1,708			
1997	1,555					1,555	1,555	1,718			
1998	1,531					1,531	1,531	1,728			
1999	1,580					1,580	1,580	1,737			
2000	1,685					1,685	1,685	1,745			
2001	1,599					1,599	1,599	1,753			
2002	1,637					1,637	1,637	1,761			
2003	1,685					1,685	1,685	1,768			
2004	1,738					1,738	1,738	1,775			
2005	1,787					1,787	1,787	1,781			
2006	1,737					1,737	1,737	1,787			
2007	1,763					1,763	1,763	1,793			
2008	1,639					1,639	1,639	1,798			
2009	1,542					1,542	1,542	1,803			

million m3 / year	FAOSTAT 2016	FAO *yearbook of forest products* 1962	FAO *yearbook of forest products* 1958	FAO yearbooks combined	Annual decrease by average annual decline of 1948-1960	Complete historical data	Historical record FAO	Trend estimate of historical record ($y = -0.2107x^2 + 31.5x + 563.46$	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
2010	1,703					1,703	1,703	1,807			
2011	1,769					1,769	1,769	1,811			
2012	1,766					1,766	1,766	1,815			
2013	1,795					1,795	1,795	1,818			
2014	1,818					1,818	1,818	1,820			
2015	1,848					1,848	1,848	1,823	1,823	1,823	1,823
2016								1,824	1,824	1,853	1,881
2017								1,826	1,826	1,870	1,915
2018								1,827	1,827	1,888	1,949
2019								1,827	1,827	1,906	1,984
2020								1,827	1,827	1,924	2,020
2021								1,827	1,827	1,937	2,046
2022								1,826	1,826	1,950	2,073
2023								1,825	1,825	1,963	2,100
2024								1,824	1,824	1,975	2,127
2025								1,822	1,822	1,988	2,155
2026								1,819	1,819	2,001	2,183
2027								1,816	1,816	2,014	2,211
2028								1,813	1,813	2,027	2,240
2029								1,809	1,809	2,039	2,269
2030								1,805	1,805	2,052	2,299

World fuelwood data and models

	FAOSTAT 2016	population (UN) '000	Annual m3 Fuelwood per capita 1961-2011	Annual trend per capita fuelwood m3 is y = 0.478e-0.012x R^2 = 0.9909	million m³			
					Trend estimate of fuelwood	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
1945		*2,279,137*		0.594	1,353			
1946		*2,329,756*		0.587	1,367			
1947		*2,380,374*		0.580	1,380			
1948		*2,430,993*		0.573	1,392			
1949		*2,481,611*		0.566	1,404			
1950		*2,532,229*		0.559	1,416			
1951		*2,580,960*		0.552	1,426			
1952		*2,628,448*		0.546	1,435			
1953		*2,675,766*		0.539	1,443			
1954		*2,723,726*		0.533	1,452			
1955		*2,772,882*		0.527	1,460			
1956		*2,823,513*		0.520	1,469			
1957		*2,875,642*		0.514	1,478			
1958		*2,929,069*		0.508	1,488			
1959		*2,983,435*		0.502	1,497			
1960		*3,038,413*		0.496	1,507			
1961	1,499	*3,093,909*	0.484	0.490	1,516			
1962	1,491	*3,150,242*	0.473	0.484	1,525			

	FAOSTAT 2016	population (UN) '000	Annual m3 Fuelwood per capita 1961-2011	Annual trend per capita fuelwood m3 is y = 0.478e-0.012x R² = 0.9909	Trend estimate of fuelwood	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
					million m³			
1963	1,501	*3,208,212*	0.468	0.478	1,535			
1964	1,513	*3,268,896*	0.463	0.473	1,545			
1965	1,514	*3,333,007*	0.454	0.467	1,557			
1966	1,526	*3,400,823*	0.449	0.461	1,569			
1967	1,529	*3,471,955*	0.440	0.456	1,583			
1968	1,531	*3,545,613*	0.432	0.451	1,597			
1969	1,529	*3,620,652*	0.422	0.445	1,612			
1970	1,542	*3,696,186*	0.417	0.440	1,586			
1971	1,550	*3,772,048*	0.411	0.435	1,599			
1972	1,564	*3,848,319*	0.406	0.429	1,612			
1973	1,565	*3,924,668*	0.399	0.424	1,624			
1974	1,585	*4,000,764*	0.396	0.419	1,636			
1975	1,592	*4,076,419*	0.390	0.414	1,647			
1976	1,615	*4,151,410*	0.389	0.409	1,657			
1977	1,623	*4,225,864*	0.384	0.404	1,667			
1978	1,633	*4,300,402*	0.380	0.400	1,676			
1979	1,662	*4,375,899*	0.380	0.395	1,685			
1980	1,682	*4,453,007*	0.378	0.390	1,695			
1981	1,703	*4,531,799*	0.376	0.385	1,704			
1982	1,744	*4,612,120*	0.378	0.381	1,714			
1983	1,746	*4,694,097*	0.372	0.376	1,723			
1984	1,767	*4,777,828*	0.370	0.372	1,733			

					million m^3			
	FAOSTAT 2016	population (UN) '000	Annual m3 Fuelwood per capita 1961-2011	Annual trend per capita fuelwood m3 is $y = 0.478e^{-0.012x}$ $R^2 = 0.9909$	Trend estimate of fuelwood	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
1985	1,771	*4,863,290*	0.364	0.367	1,743			
1986	1,780	*4,950,591*	0.360	0.363	1,753			
1987	1,775	*5,039,478*	0.352	0.359	1,763			
1988	1,792	*5,129,113*	0.349	0.354	1,773			
1989	1,801	*5,218,375*	0.345	0.350	1,783			
1990	1,827	*5,306,425*	0.344	0.346	1,791			
1991	1,863	*5,392,939*	0.346	0.342	1,798			
1992	1,835	*5,478,009*	0.335	0.338	1,805			
1993	1,803	*5,561,744*	0.324	0.334	1,811			
1994	1,795	*5,644,416*	0.318	0.330	1,816			
1995	1,798	*5,726,239*	0.314	0.326	1,820			
1996	1,782	*5,807,212*	0.307	0.322	1,824			
1997	1,801	*5,887,260*	0.306	0.318	1,827			
1998	1,796	*5,966,465*	0.301	0.314	1,829			
1999	1,801	*6,044,931*	0.298	0.311	1,831			
2000	1,771	*6,122,770*	0.289	0.307	1,833			
2001	1,773	*6,200,003*	0.286	0.303	1,834			
2002	1,796	*6,276,722*	0.286	0.300	1,834			
2003	1,807	*6,353,196*	0.284	0.296	1,835			
2004	1,809	*6,429,758*	0.281	0.292	1,835			
2005	1,799	*6,506,649*	0.276	0.289	1,834			
2006	1,809	*6,583,959*	0.275	0.286	1,834			

					million m³			
	FAOSTAT 2016	population (UN) '000	Annual m3 Fuelwood per capita 1961-2011	Annual trend per capita fuelwood m3 is $y = 0.478e^{-0.012x}$ $R^2 = 0.9909$	Trend estimate of fuelwood	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
2007	1,817	*6,661,637*	0.273	0.282	1,833			
2008	1,819	*6,739,610*	0.270	0.279	1,833			
2009	1,811	*6,817,737*	0.266	0.275	1,832			
2010	1,823	*6,895,889*	0.264	0.272	1,831			
2011	1,820	*6,974,036*	0.261	0.269	1,830			
2012	1,848	*7,052,135*	0.262	0.266	1,828			
2013	1,858	*7,130,014*	0.261	0.263	1,826			
2014	1,862	*7,207,460*	0.258	0.259	1,824			
2015	1,866	*7,284,296*	0.256	0.256	1,821	1,821	1,844	1,866
2016		*7,360,430*		0.253	1,818	1,818	1,858	1,897
2017		*7,435,810*		0.250	1,815	1,815	1,872	1,929
2018		*7,510,341*		0.247	1,811	1,811	1,887	1,962
2019		*7,583,938*		0.244	1,807	1,807	1,901	1,995
2020		*7,656,528*		0.241	1,803	1,803	1,916	2,028
2021		*7,728,046*		0.239	1,798	1,798	1,930	2,062
2022		*7,798,450*		0.236	1,793	1,793	1,945	2,097
2023		*7,867,734*		0.233	1,787	1,787	1,960	2,132
2024		*7,935,908*		0.230	1,781	1,781	1,975	2,168
2025		*8,002,978*		0.227	1,775	1,775	1,990	2,205
2026		*8,068,925*		0.225	1,768	1,768	2,005	2,242
2027		*8,133,725*		0.222	1,761	1,761	2,020	2,279
2028		*8,197,390*		0.219	1,754	1,754	2,036	2,318

	FAOSTAT 2016	population (UN) '000	Annual m3 Fuelwood per capita 1961-2011	Annual trend per capita fuelwood m3 is $y = 0.478e^{-0.012x}$ $R^2 = 0.9909$	million m³			
					Trend estimate of fuelwood	Scenario 1 - historical trend	Scenario 2 - intermediate	Scenario 3 - high growth
2029		*8,259,937*		0.217	1,746	1,746	2,051	2,357
2030		*8,321,380*		0.214	1,738	1,738	2,067	2,396

Cultivated wood models 1945- 2030

Figures in red are from sources mentioned in Chapter 5 Methods from which extrapolations were made (Brown [2000] for plantation sources and Carle and Holmgren [2008] for planted forest sources). Table was extended to 2050 to allow backward extrapolation. Details of extrapolation and assumptions are in the methods of Chapter 5.

	Plantation - Low			Plantation - High			Planted Forest - Low			Planted Forest - High			Non forest trees - Fuelwood				
million m³ per year	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - planted + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - plantation + trees not from forests	FAOSTAT data and extrapolated	Portion (low) from trees not from forests	Portion (high) from trees not from forests	Fuelwood - trees not from forests (low)	Fuelwood - trees not from forests (high)
1945	20	20	155	20	20	471	235	40	176	218	55	506	1,353	*0.1*	*0.333*	135	451
1946	20	20	162	20	20	483	245	41	183	232	56	518	1,367	*0.104*	*0.339*	142	463
1947	20	20	168	20	20	494	255	42	190	245	57	531	1,380	*0.107*	*0.344*	148	474
1948	20	20	175	20	20	506	265	43	198	259	58	544	1,392	*0.111*	*0.349*	155	486
1949	20	20	181	20	20	518	275	44	205	272	59	557	1,404	*0.115*	*0.354*	161	498
1950	20	20	188	20	20	529	285	45	213	286	60	569	1,416	*0.119*	*0.36*	168	509
1951	20	20	194	20	20	540	295	46	220	299	61	582	1,426	*0.122*	*0.365*	174	520
1952	20	20	201	20	20	551	305	47	228	313	62	593	1,435	*0.126*	*0.37*	181	531
1953	20	20	207	20	20	562	315	48	235	326	63	605	1,443	*0.13*	*0.375*	187	542
1954	20	20	214	20	20	573	325	49	242	340	65	617	1,452	*0.133*	*0.381*	194	553
1955	20	20	220	20	20	584	335	50	250	353	66	629	1,460	*0.137*	*0.386*	200	564

	Plantation - Low			Plantation - High			Planted Forest - Low			Planted Forest - High			Non forest trees - Fuelwood				
million m³ per year	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - planted + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - plantation + trees not from forests	FAOSTAT data and extrapolated	Portion (low) from trees not from forests	Portion (high) from trees not from forests	Fuelwood - trees not from forests (low)	Fuelwood - trees not from forests (high)
1956	20	20	227	20	20	595	345	51	257	367	67	642	1,469	*0.141*	*0.391*	207	575
1957	20	20	234	20	20	606	355	52	265	381	68	654	1,478	*0.145*	*0.397*	214	586
1958	20	20	241	20	20	618	365	52	273	394	69	667	1,488	*0.148*	*0.402*	221	598
1959	20	20	248	20	20	630	375	53	281	408	70	680	1,497	*0.152*	*0.407*	228	610
1960	20	20	255	20	20	641	385	54	289	421	71	692	1,507	*0.156*	*0.412*	235	621
1961	23	20	262	23	20	653	395	55	297	435	72	698	1,516	*0.159*	*0.418*	242	633
1962	26	20	269	26	20	665	405	56	305	448	73	704	1,525	*0.163*	*0.423*	249	645
1963	29	20	276	29	20	677	415	57	313	462	74	717	1,535	*0.167*	*0.428*	256	657
1964	32	20	283	32	20	690	425	58	321	475	76	732	1,545	*0.17*	*0.433*	263	670
1965	35	20	291	35	20	703	435	59	330	489	77	741	1,557	*0.174*	*0.439*	271	683
1966	38	20	299	38	20	717	445	60	339	502	78	755	1,569	*0.178*	*0.444*	279	697
1967	41	20	308	41	20	731	455	61	348	516	79	765	1,583	*0.182*	*0.449*	288	711
1968	44	20	316	44	20	746	465	62	358	529	80	776	1,597	*0.185*	*0.455*	296	726
1969	47	20	325	47	20	761	475	63	367	543	81	784	1,612	*0.189*	*0.46*	305	741
1970	50	20	333	50	20	776	485	64	377	557	82	799	1,626	*0.193*	*0.465*	313	756
1971	60	22	344	60	22	793	495	64	386	570	83	812	1,639	*0.196*	*0.47*	322	771
1972	70	24	355	70	24	810	505	65	396	584	84	828	1,652	*0.2*	*0.476*	331	786
1973	80	26	365	80	26	827	515	66	406	597	85	838	1,665	*0.204*	*0.481*	339	801
1974	90	28	376	90	28	843	525	67	415	611	87	857	1,677	*0.208*	*0.486*	348	815
1975	100	30	387	100	30	860	535	68	425	624	88	870	1,689	*0.211*	*0.491*	357	830

million m³ per year	Plantation - Low			Plantation - High			Planted Forest - Low			Planted Forest - High			Non forest trees - Fuelwood				
	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - planted + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - plantation + trees not from forests	FAOSTAT data and extrapolated	Portion (low) from trees not from forests	Portion (high) from trees not from forests	Fuelwood - trees not from forests (low)	Fuelwood - trees not from forests (high)
1976	110	32	397	110	32	876	545	69	434	638	89	891	1,699	*0.215*	*0.497*	365	844
1977	120	34	408	120	34	892	555	70	444	651	90	904	1,709	*0.219*	*0.502*	374	858
1978	130	36	418	130	36	908	565	71	453	665	91	919	1,718	*0.222*	*0.507*	382	872
1979	140	38	429	140	38	923	575	72	463	678	92	944	1,728	*0.226*	*0.512*	391	885
1980	150	40	439	150	40	939	585	73	472	692	93	964	1,737	*0.23*	*0.518*	399	899
1981	160	41	449	160	41	955	595	74	482	705	94	985	1,747	*0.234*	*0.523*	408	914
1982	170	42	459	170	42	970	605	75	491	719	95	1,017	1,757	*0.237*	*0.528*	417	928
1983	180	43	469	180	43	985	615	76	501	733	96	1,028	1,766	*0.241*	*0.534*	426	942
1984	190	44	479	190	44	1,001	625	76	511	746	98	1,050	1,776	*0.245*	*0.539*	435	957
1985	200	45	489	200	45	1,017	635	77	521	760	99	1,062	1,787	*0.248*	*0.544*	444	972
1986	210	46	499	210	46	1,033	645	78	531	773	100	1,078	1,797	*0.252*	*0.549*	453	987
1987	220	47	509	220	47	1,049	655	79	542	787	101	1,085	1,808	*0.256*	*0.555*	462	1,002
1988	230	48	520	230	48	1,066	665	80	552	800	102	1,105	1,818	*0.26*	*0.56*	472	1,018
1989	240	49	530	240	49	1,082	675	81	562	814	103	1,121	1,827	*0.263*	*0.565*	481	1,033
1990	250	50	540	250	50	1,097	685	82	572	827	104	1,146	1,836	*0.267*	*0.57*	490	1,047
1991	266	57	556	266	57	1,119	695	83	582	841	105	1,178	1,844	*0.271*	*0.576*	499	1,061
1992	282	65	572	282	65	1,140	715	85	592	868	107	1,173	1,850	*0.274*	*0.581*	508	1,075
1993	299	72	588	299	72	1,160	736	87	603	895	110	1,167	1,856	*0.278*	*0.586*	516	1,088
1994	315	79	604	315	79	1,180	756	88	613	922	112	1,174	1,861	*0.282*	*0.592*	524	1,101
1995	331	86	619	331	86	1,200	776	90	623	949	114	1,187	1,866	*0.285*	*0.597*	533	1,113

	Plantation - Low			Plantation - High			Planted Forest - Low			Planted Forest - High			Non forest trees - Fuelwood				
million m³ per year	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - planted + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - plantation + trees not from forests	FAOSTAT data and extrapolated	Portion (low) from trees not from forests	Portion (high) from trees not from forests	Fuelwood - trees not from forests (low)	Fuelwood - trees not from forests (high)
1996	348	95	636	348	95	1,221	796	92	633	976	116	1,189	1,870	*0.289*	*0.602*	541	1,126
1997	364	104	653	364	104	1,241	816	94	643	1,003	118	1,212	1,873	*0.293*	*0.607*	549	1,137
1998	381	113	669	381	113	1,262	836	96	652	1,030	121	1,221	1,875	*0.297*	*0.613*	556	1,149
1999	398	122	686	398	122	1,282	856	98	662	1,058	123	1,236	1,877	*0.3*	*0.618*	564	1,160
2000	415	131	702	415	131	1,301	876	100	671	1,085	125	1,228	1,879	*0.304*	*0.623*	571	1,171
2001	432	134	712	437	138	1,319	896	101	680	1,112	127	1,241	1,880	*0.308*	*0.628*	579	1,181
2002	450	137	723	459	145	1,336	916	103	689	1,139	129	1,268	1,880	*0.311*	*0.634*	586	1,192
2003	468	140	733	482	152	1,354	936	105	698	1,166	132	1,286	1,881	*0.315*	*0.639*	593	1,202
2004	486	143	743	504	159	1,371	956	107	707	1,193	134	1,299	1,881	*0.319*	*0.644*	600	1,211
2005	504	147	753	526	167	1,388	976	109	715	1,220	136	1,304	1,880	*0.323*	*0.649*	607	1,221
2006	522	150	763	549	174	1,405	996	111	724	1,247	138	1,322	1,880	*0.326*	*0.655*	613	1,231
2007	540	153	773	571	181	1,421	1,016	112	733	1,274	140	1,340	1,880	*0.33*	*0.66*	620	1,240
2008	558	156	783	593	188	1,438	1,036	114	741	1,301	143	1,352	1,879	*0.334*	*0.665*	627	1,250
2009	575	160	793	616	195	1,455	1,056	116	750	1,328	145	1,359	1,878	*0.337*	*0.671*	634	1,259
2010	593	163	803	638	203	1,471	1,076	118	758	1,355	147	1,379	1,877	*0.341*	*0.676*	640	1,268
2011	606	165	812	670	213	1,490	1,096	120	767	1,382	149	1,389	1,875	*0.345*	*0.681*	647	1,277
2012	620	168	821	702	223	1,509	1,116	122	775	1,410	151	1,420	1,874	*0.349*	*0.686*	653	1,286
2013	633	170	829	735	232	1,527	1,136	124	783	1,437	154	1,438	1,872	*0.352*	*0.692*	659	1,295
2014	646	172	838	767	242	1,545	1,156	125	791	1,464	156	1,453	1,870	*0.356*	*0.697*	666	1,303
2015	659	175	846	799	252	1,563	1,176	127	799	1,491	158	1,468	1,867	*0.36*	*0.702*	672	1,311

million m³ per year	Plantation - Low			Plantation - High			Planted Forest - Low			Planted Forest - High			Non forest trees - Fuelwood				
	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - planted + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - plantation + trees not from forests	FAOSTAT data and extrapolated	Portion (low) from trees not from forests	Portion (high) from trees not from forests	Fuelwood - trees not from forests (low)	Fuelwood - trees not from forests (high)
2016	672	177	854	831	262	1,581	1,196	129	807	1,518	160	1,447	1,864	0.363	0.707	677	1,319
2017	685	179	862	863	272	1,599	1,216	131	814	1,545	162	1,456	1,861	0.367	0.713	683	1,326
2018	698	182	870	895	282	1,616	1,237	133	821	1,572	165	1,465	1,857	0.371	0.718	689	1,333
2019	711	184	878	927	292	1,632	1,257	135	829	1,599	167	1,474	1,853	0.375	0.723	694	1,340
2020	724	187	886	959	302	1,649	1,277	137	836	1,626	169	1,482	1,848	0.378	0.728	699	1,346
2021	729	189	893	977	309	1,661	1,297	138	842	1,653	171	1,491	1,843	0.382	0.734	704	1,352
2022	734	191	899	996	315	1,673	1,317	140	849	1,680	173	1,498	1,838	0.386	0.739	709	1,358
2023	739	193	906	1,014	321	1,684	1,337	142	855	1,707	176	1,506	1,832	0.389	0.744	713	1,364
2024	743	195	912	1,032	327	1,696	1,357	144	862	1,735	178	1,513	1,826	0.393	0.75	718	1,369
2025	748	197	919	1,050	333	1,706	1,377	146	868	1,762	180	1,520	1,819	0.397	0.755	722	1,373
2026	753	199	925	1,068	339	1,717	1,397	148	873	1,789	182	1,526	1,812	0.4	0.76	726	1,378
2027	758	201	930	1,086	345	1,727	1,417	149	879	1,816	184	1,532	1,805	0.404	0.765	730	1,382
2028	763	203	936	1,104	352	1,737	1,437	151	885	1,843	187	1,538	1,798	0.408	0.771	733	1,385
2029	767	205	942	1,122	358	1,746	1,457	153	890	1,870	189	1,543	1,790	0.412	0.776	737	1,389
2030	772	207	947	1,140	364	1,756	1,477	155	895	1,897	191	1,549	1,782	0.415	0.781	740	1,392
2031	777	209		1,158	370												
2032	782	211		1,176	376												
2033	787	213		1,194	382												
2034	791	215		1,212	389												
2035	796	217		1,230	395												

million m³ per year	Plantation - Low			Plantation - High			Planted Forest - Low			Planted Forest - High			Non forest trees - Fuelwood				
	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - plantation	Total fuelwood - plantation + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - planted + trees not from forests	industrial roundwood	Fuelwood - planted	Total fuelwood - plantation + trees not from forests	FAOSTAT data and extrapolated	Portion (low) from trees not from forests	Portion (high) from trees not from forests	Fuelwood - trees not from forests (low)	Fuelwood - trees not from forests (high)
2036	801	219		1,248	401												
2037	806	221		1,266	407												
2038	810	223		1,284	413												
2039	815	225		1,302	419												
2040	820	227		1,320	426												
2041	825	229		1,338	432												
2042	830	231		1,356	438												
2043	834	233		1,374	444												
2044	839	235		1,392	450												
2045	844	237		1,410	456												
2046	849	239		1,428	462												
2047	853	241		1,446	469												
2048	858	243		1,464	475												
2049	863	245		1,482	481												
2050	868	247		1,500	487												

Total cultivated wood and natural forest wood for 1945-2015

Modelled cultivated wood production for plantations and planted forests (including wood from trees outside of forests in both cases) and the remainder of wood production which is called natural forest. This is the result of subtracting the cultivated wood model figure (plantation or planted forest) from the total roundwood figure.

million m3		Plantation - Low		Plantation - High		Planted Forest - High		Planted Forest - High	
Year	Total roundwood	Plantation - Low bound	Natural forest	Plantation - High bound	Natural forest	Planted forest - Low bound	Natural forest	Planted forest - High bound	Natural forest
1945	1,959	175	1,783	491	1,468	410	1,548	724	1,235
1946	2,000	182	1,818	503	1,497	428	1,573	750	1,250
1947	2,041	188	1,853	514	1,527	445	1,596	776	1,265
1948	2,082	195	1,887	526	1,556	462	1,619	803	1,279
1949	2,075	201	1,874	538	1,538	480	1,595	829	1,246
1950	2,135	208	1,927	549	1,586	498	1,637	855	1,280
1951	2,210	214	1,996	560	1,650	515	1,695	881	1,329
1952	2,221	221	2,001	571	1,650	532	1,689	906	1,315
1953	2,217	227	1,990	582	1,635	550	1,667	932	1,285
1954	2,291	234	2,057	593	1,698	567	1,724	957	1,334
1955	2,374	240	2,134	604	1,770	585	1,789	983	1,391
1956	2,412	247	2,165	615	1,797	602	1,810	1,009	1,404
1957	2,413	254	2,159	626	1,787	620	1,793	1,035	1,378

million m3		Plantation - Low		Plantation - High		Planted Forest - High		Planted Forest - High	
Year	Total roundwood	Plantation - Low bound	Natural forest	Plantation - High bound	Natural forest	Planted forest - Low bound	Natural forest	Planted forest - High bound	Natural forest
1958	2,426	261	2,165	638	1,788	638	1,788	1,061	1,365
1959	2,499	268	2,231	650	1,849	656	1,843	1,087	1,412
1960	2,533	275	2,259	661	1,872	674	1,859	1,114	1,420
1961	2,517	282	2,235	669	1,848	689	1,828	1,133	1,384
1962	2,527	289	2,238	677	1,851	704	1,823	1,152	1,375
1963	2,551	299	2,252	692	1,859	722	1,829	1,179	1,372
1964	2,624	310	2,314	708	1,916	741	1,884	1,207	1,418
1965	2,646	319	2,327	719	1,926	758	1,888	1,230	1,416
1966	2,679	330	2,350	736	1,944	776	1,903	1,258	1,422
1967	2,711	339	2,372	748	1,963	793	1,917	1,281	1,429
1968	2,737	348	2,389	760	1,977	810	1,926	1,305	1,431
1969	2,763	356	2,407	770	1,993	827	1,937	1,327	1,436
1970	2,819	367	2,452	787	2,032	846	1,973	1,356	1,463
1971	2,847	387	2,460	811	2,036	864	1,983	1,382	1,464
1972	2,854	407	2,447	838	2,016	884	1,971	1,412	1,442
1973	2,924	425	2,499	859	2,066	900	2,024	1,435	1,489
1974	2,936	447	2,489	888	2,047	921	2,014	1,468	1,468
1975	2,886	466	2,419	912	1,974	940	1,946	1,494	1,392
1976	2,984	489	2,495	944	2,040	961	2,023	1,528	1,456
1977	3,001	509	2,492	969	2,033	980	2,021	1,556	1,446
1978	3,055	529	2,526	994	2,061	999	2,056	1,584	1,471

million m3		Plantation - Low		Plantation - High		Planted Forest - High		Planted Forest - High	
Year	Total roundwood	Plantation - Low bound	Natural forest	Plantation - High bound	Natural forest	Planted forest - Low bound	Natural forest	Planted forest - High bound	Natural forest
1979	3,120	554	2,566	1,030	2,090	1,023	2,097	1,622	1,498
1980	3,128	576	2,551	1,061	2,067	1,044	2,083	1,656	1,472
1981	3,115	599	2,516	1,092	2,023	1,067	2,048	1,691	1,425
1982	3,116	626	2,490	1,133	1,983	1,094	2,022	1,736	1,380
1983	3,202	644	2,558	1,155	2,047	1,112	2,090	1,761	1,441
1984	3,288	666	2,622	1,186	2,102	1,134	2,154	1,796	1,492
1985	3,294	685	2,610	1,209	2,086	1,153	2,142	1,822	1,473
1986	3,372	705	2,667	1,234	2,138	1,172	2,200	1,851	1,521
1987	3,428	721	2,707	1,251	2,176	1,189	2,239	1,872	1,556
1988	3,465	743	2,722	1,281	2,183	1,211	2,254	1,905	1,559
1989	3,503	763	2,740	1,307	2,196	1,231	2,273	1,935	1,569
1990	3,536	788	2,749	1,342	2,194	1,255	2,281	1,974	1,563
1991	3,433	828	2,605	1,396	2,036	1,283	2,150	2,019	1,414
1992	3,339	850	2,489	1,413	1,927	1,304	2,036	2,041	1,298
1993	3,288	872	2,416	1,428	1,860	1,324	1,964	2,062	1,226
1994	3,280	900	2,380	1,456	1,824	1,350	1,930	2,096	1,184
1995	3,325	931	2,394	1,491	1,834	1,379	1,945	2,136	1,188
1996	3,287	958	2,328	1,516	1,771	1,403	1,884	2,165	1,121
1997	3,356	996	2,360	1,562	1,794	1,437	1,919	2,215	1,141
1998	3,327	1,027	2,300	1,594	1,733	1,464	1,863	2,251	1,076
1999	3,381	1,061	2,321	1,633	1,749	1,494	1,887	2,293	1,088

million m³		Plantation - Low		Plantation - High		Planted Forest - High		Planted Forest - High	
Year	Total roundwood	Plantation - Low bound	Natural forest	Plantation - High bound	Natural forest	Planted forest - Low bound	Natural forest	Planted forest - High bound	Natural forest
2000	3,456	1,083	2,372	1,648	1,807	1,514	1,942	2,313	1,143
2001	3,372	1,112	2,260	1,689	1,683	1,543	1,829	2,353	1,019
2002	3,434	1,147	2,287	1,742	1,691	1,579	1,855	2,406	1,027
2003	3,492	1,178	2,314	1,788	1,704	1,610	1,882	2,452	1,040
2004	3,547	1,206	2,341	1,829	1,718	1,640	1,907	2,492	1,055
2005	3,585	1,231	2,354	1,861	1,724	1,665	1,920	2,524	1,061
2006	3,545	1,262	2,284	1,907	1,639	1,697	1,849	2,569	976
2007	3,581	1,293	2,288	1,952	1,629	1,728	1,852	2,614	967
2008	3,458	1,321	2,137	1,991	1,466	1,757	1,700	2,654	804
2009	3,352	1,346	2,006	2,025	1,327	1,783	1,569	2,687	665
2010	3,526	1,378	2,148	2,073	1,454	1,816	1,710	2,735	792
2011	3,589	1,399	2,190	2,123	1,467	1,844	1,745	2,771	818
2012	3,614	1,431	2,183	2,193	1,421	1,882	1,732	2,829	785
2013	3,652	1,457	2,195	2,252	1,400	1,914	1,738	2,875	777
2014	3,680	1,481	2,199	2,307	1,373	1,945	1,735	2,917	763
2015	3,714	1,505	2,209	2,361	1,352	1,975	1,739	2,959	755

Forecast wood production 2016-2030

Scenarios 1-3 are three forecasts of total roundwood. Methods are described in Chapter 5. The plantation and planted forest high and low models are also described in Chapter 5. Below that are the three natural wood forecasts based on subtracting the applicable cultivated wood source wood volume from each total roundwood scenario.

million m^3		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Scenario 1	Total roundwood - trend	3,688	3,686	3,684	3,680	3,676	3,670	3,664	3,657	3,649	3,641	3,632	3,621	3,611	3,599	3,587
Scenario 2	Total roundwood - intermediate	3,712	3,745	3,778	3,812	3,846	3,874	3,904	3,933	3,962	3,991	4,021	4,051	4,080	4,111	4,141
Scenario 3	Total roundwood - high growth	3,736	3,804	3,873	3,944	4,016	4,079	4,143	4,208	4,274	4,342	4,410	4,480	4,550	4,622	4,695
Cultivated wood source	Plantation - Low	1,526	1,548	1,569	1,589	1,610	1,622	1,633	1,645	1,656	1,667	1,678	1,688	1,699	1,709	1,719
	Plantation - High	2,412	2,462	2,511	2,560	2,608	2,639	2,668	2,698	2,727	2,756	2,785	2,813	2,841	2,868	2,895
	Planted - Low	2,003	2,031	2,058	2,085	2,112	2,139	2,166	2,192	2,218	2,244	2,270	2,296	2,321	2,347	2,372
	Planted - High	2,355	2,390	2,425	2,460	2,494	2,528	2,563	2,596	2,630	2,663	2,697	2,730	2,763	2,795	2,828
Plantation - Low	Scenario 1	2,162	2,139	2,115	2,091	2,066	2,048	2,031	2,012	1,994	1,974	1,954	1,933	1,912	1,890	1,868
	Scenario 2	2,186	2,198	2,210	2,223	2,236	2,253	2,270	2,288	2,306	2,324	2,343	2,362	2,382	2,402	2,422
	Scenario 3	2,209	2,256	2,305	2,354	2,406	2,457	2,510	2,563	2,619	2,675	2,732	2,791	2,852	2,913	2,976
Plantation - High	Scenario 1	1,276	1,225	1,173	1,120	1,067	1,032	996	959	922	885	847	809	770	731	691
	Scenario 2	1,300	1,283	1,268	1,252	1,237	1,236	1,235	1,235	1,235	1,235	1,236	1,238	1,240	1,242	1,245
	Scenario 3	1,324	1,342	1,362	1,384	1,407	1,440	1,474	1,510	1,547	1,586	1,625	1,667	1,710	1,754	1,800
Planted - low	Scenario 1	1,685	1,656	1,626	1,595	1,563	1,531	1,498	1,465	1,431	1,396	1,361	1,325	1,289	1,252	1,215
	Scenario 2	1,709	1,715	1,720	1,727	1,733	1,736	1,738	1,741	1,744	1,747	1,751	1,755	1,759	1,764	1,769
	Scenario 3	1,733	1,773	1,815	1,859	1,904	1,940	1,977	2,016	2,056	2,097	2,140	2,184	2,229	2,275	2,323
Planted - high	Scenario 1	592	553	514	475	435	395	354	312	271	228	186	143	99	55	11
	Scenario 2	703	698	694	691	687	680	673	666	659	653	648	643	638	634	630
	Scenario 3	814	843	874	906	940	965	991	1,019	1,048	1,078	1,110	1,143	1,177	1,213	1,249

Appendix F. Data for Chapter 6

The data in this appendix is for Chapter 6. It replicates the supplementary materials provided for the paper 'Forest conservation, wood production intensification and leakage; An Australian case', published in *Land Use Policy* (Warman and Nelson 2016). Copyright for this material rests with the publisher, Elsevier.

Data for Figure 16

Housing starts data from Australian Bureau of Statistics Table 8752.0, Series A83794704W (Sum of four quarters ending June in each year). GDP per capita data from Australian Bureau of Statistics Table 5206.0 , Series A2305001C. Estimated logs consumed data provided in customised data table from ABARES 27 June 2015.

million m^3	**1996-97**	**1997-98**	**1998-99**	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**
Housing starts '000	86.3	101.3	102.7	113.8	81.2	113.6	116.4	119.2	106.5	104.8	106.9	107.3	94	115.5	101	90.1	92.8	104.7
GDP per capita '000 ($AUD)	49.7	51.4	53.4	54.8	55.2	56.6	57.7	59.4	60.7	61.7	63	64.1	63.8	63.9	64.5	65.9	66.4	66.9
Sawlog consumption million m^3	12	12.7	12.6	14.2	13.1	13.7	14.4	15.1	14.9	14.5	13.9	15	12.5	13.6	12.9	12.1	11.7	12
Pulplog consumption million m^3	6.9	6.5	6.4	6.8	6.3	6.5	7.2	7.2	7.1	6.8	7.2	7.8	7.2	7.2	7.9	7.4	7.1	6.9

Data for Figure 17

Estimated native (natural) forest log production provided in customised data table from ABARES 27 July 2015 for period until 2011-12. Years 2012-13 and 20 13-14 were calculated based on each state's land agency's published annual reports. It did not include Cypress in Queensland or New South Wales or peelers or special species in Tasmania, consistent with the 2013 ABARES dataset.

Natural forest logs million m^3	**1996-97**	**1997-98**	**1998-99**	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**
Sawlogs, public	3.02	2.93	2.92	2.94	2.60	2.58	2.41	2.29	2.17	2.08	1.99	2.00	1.73	1.65	1.46	1.41	1.48	1.37
Sawlogs, private	0.93	0.89	0.93	0.92	0.86	0.93	0.92	0.94	0.93	0.95	0.69	0.73	0.66	0.51	0.37	0.35	0.17	0.23
Pulplogs, public	3.61	3.87	3.54	4.46	4.90	4.22	4.70	4.84	4.66	4.17	4.27	4.52	3.96	3.30	3.32	1.89	1.59	1.79
Pulplogs, private	1.55	2.06	1.72	2.51	2.10	1.80	1.91	1.62	1.69	1.01	1.09	1.25	0.99	0.64	0.57	0.21	0.07	0.28
% of total natural forest log production																		
Public	73%	70%	71%	68%	72%	71%	72%	74%	72%	76%	78%	77%	77%	81%	84%	85%	93%	86%
Private	27%	30%	29%	32%	28%	29%	28%	26%	28%	24%	22%	23%	23%	19%	16%	15%	7%	14%

Data for broadleaved native logs provided in customised data table from ABARES 27 July 2015. Data for cypress pine native forest logs provided in customised data table from ABARES 14 July 2014 and for 2013-14 the amount was estimated based on dividing the national total by the average ratio of New South Wales cypress logs to Queensland cypress logs for the previous three years.

Natural forest logs **million m³**	**1996-97**	**1997-98**	**1998-99**	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**% decline 96/97 to 13/14**
NSW Broadleaved native	2.0	1.9	1.7	1.9	1.9	1.7	1.9	1.9	1.8	1.9	1.8	1.7	1.4	1.4	1.1	1.1	0.9	0.9	
NSW Cypress native	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	
New South Wales	2.2	2.0	1.8	2.0	2.0	1.9	2.0	2.0	1.9	2.0	1.9	1.8	1.5	1.4	1.1	1.2	1.0	0.9	57%
QLD Broadleaved native	0.5	0.5	0.5	0.5	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	
QLD Cypress native	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	
Queensland	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.4	0.4	45%
Victoria	2.1	2.3	2.3	2.5	2.4	2.4	2.1	2.0	2.1	2.0	1.8	2.0	1.8	1.9	1.8	1.5	1.3	1.4	34%
Tasmania	3.2	4.0	3.7	5.3	5.1	4.6	5.3	5.2	5.1	3.8	4.0	4.3	3.7	2.7	2.7	1.0	0.8	1.1	65%
West Australia	1.4	1.3	1.2	1.0	1.0	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.3	75%

Data for Figure 18

Data for broadleaved native logs provided in customised data table from ABARES 27 July 2015. Data for cypress pine native forest logs provided in customised data table from ABARES 14 July 2014 and for 2013-14 the amount was estimated based on dividing the national total by the average ratio of New South Wales cypress logs to Queensland cypress logs for the previous three years.

Sawlogs **million m³**	1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
NSW Broadleaved native	1.3	1.2	1.2	1.3	1.2	1.3	1.3	1.4	1.3	1.4	1.2	1.1	1.0	0.9	0.6	0.7	0.6	0.6
NSW Cypress native	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0
New South Wales	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.5	1.4	1.4	1.3	1.2	1.0	0.9	0.6	0.7	0.7	0.6
QLD Broadleaved native	0.5	0.5	0.5	0.5	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
QLD Cypress native	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Queensland	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.4	0.4
Victoria	1.0	1.1	1.2	1.1	0.9	1.0	0.9	0.7	0.7	0.6	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Tasmania	0.6	0.5	0.6	0.6	0.6	0.6	0.7	0.8	0.7	0.6	0.7	0.7	0.6	0.6	0.7	0.6	0.4	0.4
West Australia	0.7	0.6	0.6	0.6	0.6	0.5	0.4	0.4	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.3	0.2
Aust..sawlog consumption	12.0	12.7	12.6	14.2	13.1	13.7	14.4	15.1	14.9	14.5	13.9	15.0	12.5	13.6	12.9	12.1	11.7	12.0
Aust. hardwood sawlog consumption	4.4	4.3	4.5	4.6	4.1	4.2	4.2	4.3	4.2	4.1	3.9	3.8	3.1	3.0	2.7	2.8	2.5	2.1
Aust. plantation production	6.0	6.7	6.7	7.7	7.8	8.4	8.8	9.4	9.5	9.7	9.9	10.0	8.9	9.9	9.3	8.6	8.7	9.7

Data for broadleaved natural forest pulplog production and pulplog consumption provided in customised data table from ABARES 27 July 2015.

Pulplogs **million m³**	**1996-97**	**1997-98**	**1998-99**	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**
New South Wales	0.7	0.6	0.5	0.5	0.6	0.5	0.6	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.3	0.3
Queensland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Victoria	1.1	1.2	1.1	1.3	1.5	1.4	1.2	1.3	1.3	1.4	1.3	1.4	1.2	1.3	1.3	1.0	0.8	0.9
Tasmania	2.7	3.4	3.1	4.6	4.5	4.0	4.6	4.4	4.4	3.1	3.3	3.6	3.1	2.0	1.9	0.4	0.4	0.8
West Australia	0.7	0.7	0.5	0.5	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1
National consumption	6.3	6.0	5.4	5.8	5.3	5.4	6.1	6.1	6.1	5.8	6.2	6.8	6.4	6.5	7.2	6.8	7.0	6.9
National hardwood consumption	2.2	2.3	2.0	2.1	1.9	1.8	1.9	2.1	2.2	2.0	2.1	2.3	2.1	2.0	2.0	2.0	2.0	2.0
National plantation	4.5	4.3	4.6	5.3	5.6	5.7	6.4	6.7	7.4	8.1	8.5	9.2	8.9	8.9	10.8	10.4	10.2	11.4
Total production	9.7	10.2	9.8	12.3	12.6	11.8	13.0	13.2	13.7	13.3	13.9	15.0	13.9	12.9	14.7	12.4	11.9	13.5

Data for Figure 19

Net trade whole log equivalents. Data derived from above.

Net trade whole log equivalents **million m³**	**1996-97**	**1997-98**	**1998-99**	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**
sawlog	-1.61	-1.75	-1.63	-2.07	-1.20	-1.14	-1.59	-1.83	-1.61	-1.10	-0.56	-1.55	-0.61	-0.85	-0.99	-0.93	-0.79	-0.19
pulplog	3.41	4.22	4.44	6.47	7.34	6.39	6.96	7.10	7.64	7.51	7.69	8.19	7.52	6.34	7.42	5.64	4.84	6.58
logs for net furniture trade	-0.13	-0.16	-0.19	-0.23	-0.24	-0.27	-0.33	-0.43	-0.56	-0.66	-0.70	-0.75	-0.70	-0.72	-1.19	-1.56	-1.52	-1.52
all logs (saw, pulp and net furniture trade	1.66	2.31	2.63	4.16	5.90	4.98	5.03	4.85	5.47	5.76	6.44	5.90	6.21	4.77	5.23	3.15	2.53	4.87

Data for trade in secondary products

Data for trends in trade for secondary wood products came from ABARES biannual report, *Australian Forest and Wood Products Statistics* for March and June quarters 2014 for Paper Manufactures and for September and December quarters 2015 for printed articles, wooden furniture and prefabricated buildings.

Net trade in secondary wood products Current prices $ '000	Printed articles	Paper manufactures	Wooden furniture	Prefabricated buildings
1996-97	574,425	144,145	199,485	-23,753
1997-98	674,439	173,282	276,656	-27,484
1998-99	715,854	202,300	325,246	-22,329
1999-00	703,566	206,413	441,078	-5,634
2000-01	711,049	202,184	472,920	-19,287
2001-02	714,709	164,467	495,863	-39,099
2002-03	723,957	189,595	613,919	-37,372
2003-04	689,299	191,783	693,195	-6,875
2004-05	709,672	269,347	884,741	-5,485
2005-06	719,926	300,702	1,014,671	-4,985
2006-07	726,390	357,893	1,145,622	10,092
2007-08	766,748	409,843	1,230,522	1,158
2008-09	848,224	484,133	1,373,449	45,251
2009-10	710,265	460,376	1,265,483	19,473
2011-12	687,898	444,754	1,263,117	139,054
2011-12	740,805	352,339	1,337,717	403,844
2012-13	691,384	311,744	1,337,741	321,686
2013-14	751,044		1,589,353	124,366

Data for trade in wooden furniture volumes came from COMTRADE commodity codes 940161, 940169, 940360, 940350, 940340, 940330 downloaded 31st December 2014 except for 2014 data downloaded in June 2015.

Calendar year	Exports (kg)	Imports (kg)	Converted for missing import data ^1	Net imports (kg)	Whole log equivalent (m3) ^2	Financial year	Estimate for financial year ('000 m3)
1996	7,723,118	-	52,496,067	37,049,831	91,445		
1997	6,921,695	-	64,149,044	57,227,349	160,237	1996-97	131.99
1998	8,357,941	-	67,544,533	59,186,592	165,722	1997-98	162.98
1999	7,077,040	-	82,572,034	75,494,994	211,386	1998-99	188.55
2000	5,517,247	94,809,146		89,291,899	250,017	1999-00	230.70
2001	6,607,573	90,052,966		83,445,393	233,647	2000-01	241.83
2002	10,121,267	117,068,577		106,947,310	299,452	2001-02	266.55
2003	10,757,581	141,486,888		130,729,307	366,042	2002-03	332.75
2004	10,450,128	185,424,681		174,974,553	489,929	2003-04	427.99
2005	11,271,442	239,788,087		228,516,645	639,847	2004-05	564.89
2006	12,143,420	252,984,038		240,840,618	674,354	2005-06	657.10
2007	8,130,126	265,169,042		257,038,916	719,709	2006-07	697.03
2008	4,441,434	280,294,622		275,853,188	772,389	2007-08	746.05
2009	3,363,622	228,701,146		225,337,524	630,945	2008-09	701.67
2010	4,027,520	292,653,821		288,626,301	808,154	2009-10	719.55
2011	2,749,018	567,298,375		564,549,357	1,580,738	2011-12	1,194.45
2012	2,513,043	552,838,957		550,325,914	1,540,913	2011-12	1,560.83
2013	2,409,380	539,247,202		536,837,822	1,503,146	2012-13	1,522.03
2014	3,647,558	552,946,326		549,298,768	1,538,037	2013-14	1,520.59

^1 - based on ratio of $ value of imports to kg value for years 2000 -2013 applied to kg values for 1996-1999

^2 - based on conversion factor of 1.4 m3 to each tonne and conversion factor of x2 converting furniture wood volume to whole log equivalent from OECD report by Contreras-Hermosilla, Doornbosch, and Lodge (2007) .

Net export of whole hardwood sawlogs from sawnwood trade

Data for net trade in sawnwood from *Australian Forest and Wood Products Statistics* for September and December quarters 2015.

Whole log equivalents estimated using conversion figures from Jaakko Poyry (1999 p.38) — 45% of whole log to rough dressed and 30.6% of whole log for dressed timber (68% of 45%).

'000 m^3	Net trade whole log equivalent (Annual total)
1996-97	- 203.5
1997-98	- 234.1
1998-99	- 234.0
1999-00	- 247.3
2000-01	- 215.8
2001-02	- 192.1
2002-03	- 209.9
2003-04	- 299.4
2004-05	- 157.8
2005-06	- 249.5
2006-07	- 226.7
2007-08	- 195.8
2008-09	- 120.6
2009-10	- 110.1
2011-12	- 56.0
2011-12	- 115.1
2012-13	- 117.6
2013-14	72.9

Long term per capita wood consumption for Australia

Data till 2008-09 from ABARES file ACS_2010_Forestry_Tables.xls

(http://data.daff.gov.au/data/warehouse/pe_abares99001762/ACS_2010_Forestry_Tables.xls). Other data from ABARES *Australian Forest and Wood Products Statistics* for September and December quarters 2015.

	Consumption of wood '000 m3	Consumption per person (m3/yr)	Annual change
1966-67	15,023	1.27	
1967-68	15,520	1.29	-0.019
1968-69	15,613	1.27	0.019
1969-70	16,019	1.28	-0.008
1970-71	16,375	1.25	0.028
1971-72	15,799	1.19	0.066
1972-73	16,413	1.22	-0.028
1973-74	15,735	1.15	0.069
1974-75	16,030	1.15	-0.007
1975-76	14,826	1.06	0.097
1976-77	16,136	1.14	-0.080
1977-78	15,561	1.08	0.053
1978-79	15,298	1.05	0.030
1979-80	16,068	1.09	-0.040
1980-81	17,362	1.16	-0.070
1981-82	17,030	1.12	0.042
1982-83	14,147	0.92	0.203
1983-84	16,496	1.06	-0.140
1984-85	19,256	1.22	-0.161

1985-86	19,014	1.19	0.033
1986-87	17,226	1.06	0.128
1987-88	19,088	1.15	-0.095
1988-89	20,604	1.23	-0.071
1989-90	20,245	1.19	0.039
1990-91	17,904	1.04	0.150
1991-92	18,256	1.04	-0.008
1992-93	19,258	1.09	-0.047
1993-94	19,754	1.11	-0.016
1994-95	20,499	1.13	-0.028
1995-96	18,759	1.02	0.110
1996-97	19,117	1.03	-0.008
1997-98	18,957	1.01	0.019
1998-99	18,941	1.00	0.012
1999-00	21,765	1.14	-0.136
2000-01	19,772	1.02	0.118
2001-02	19,047	0.97	0.049
2002-03	20,154	1.01	-0.044
2003-04	21,671	1.08	-0.064
2004-05	22,291	1.09	-0.016
2005-06	21,674	1.05	0.046
2006-07	20,934	0.99	0.054
2007-08	22,949	1.07	-0.074
2008-09	20,483	0.93	0.135
2009-10	20,769	0.94	-0.007
2010-11	20,760	0.93	0.010
2011-12	19,555	0.86	0.070
2012-13	18,830	0.81	0.050
2013-14	18,908	0.80	0.010
Annual decrease 1996-97 to 13/14		0.012	
Annual decrease until 1996/97		0.009	

END PAGE

When timber production comes out of the woods: Post-forestry states in wood and forest socio-ecological systems

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